GMM3.0

Green Maritime Methanol
www.greenmaritimemethanol.nl

WP1 Safety Aspects: Methanol Tank Cofferdam

ABS

Acta Marine

Boskalis

BOVAG

BUREAU VERITAS 1828
Shaping a World of Trust

C-JOB
DEDICATED NAVAL ARCHITECTS

CATERPILLAR

chemgas

CORNELIS VROLIJK

DAMEN

DEME

FEADSHIP
ROYAL DUTCH SHIPYARDS

H
MARINE CONTRACTORS

KONINKLIJKE VERENIGING VAN NEDERLANDSE REDERS

Lloyd's Register

MAERSK

MARIN

MARINE SERVICE NOORD
Taking care of maritime piping.

METHANOL INSTITUTE

Ministerie van Defensie

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

BUILT BY
oceAnco

pon CAT

Port of Amsterdam

SANLORENZO

Seatrade

thyssenkrupp

TNO

TU Delft

UNIVERSITEIT GENT

Van Oord
Marine ingenuity

VICTROL

FincoEnergies

IHC

GROOT SHIP DESIGN

mtu
A Rolls-Royce solution

Report number	TNO 2025 R10154
Report date	1 April 2025
Title	WP1 Safety Aspects
Subtitle	Methanol Tank Cofferdam
Author(s)	K. Runge, F. Bziker
Number of pages	25
Project name	Green Maritime Methanol 3.0
Project number	060.56501
Classification	TNO Public

Contents

1 Introduction

1.1 Project Background

The maritime sector is facing a major challenge. While a globally growing economy leads to more demand for transport of goods, the goals from the Paris climate agreement and the subsequent agreement in IMO require a 70% reduction of CO_2-emissions from maritime transport by 2050 compared to 2008. Several parties are working on the development of new fuel types for shipping, such as methanol, hydrogen, various biofuels and battery-electric. There is great uncertainty about the best option for the short and longer term, and what the best options are for different ship segments.

Within the Green Maritime Methanol 1 and 2 projects, sector wide consortia of respectively 30 and 37 partners, have investigated the feasibility of application of methanol as a marine fuel. The main goal of the Green Maritime Methanol projects is to identify and remove barriers that stand in the way of methanol implementation.

For Green Maritime Methanol 3.0 the following objectives have been defined:

- Develop solutions for current safety issues when applying methanol.
- Broaden the knowledge on single methanol fuel solutions for on-board powertrains on-board of ships.
- Understand the design barriers for different ship types by developing new ship design pilots.
- Understand the most important barriers (technology, economics and policy) towards investment decisions aimed at large scale adoption of methanol in shipping.

1.2 Aim of this document

The focus in WP1 lies on the safety aspects. When ship owners decide to design a new-built vessel or convert an existing vessel for methanol fuelled power generation systems, prescriptive rules are not yet available. In lieu, the framework of alternative design and preliminary guidelines are being used. The flag state has the final say in many cases: “to the satisfaction of the administration”. Currently, additional cofferdams are required depending on the location of the methanol tank. These cofferdams are added for safety based on prescriptive regulatory frameworks and rule sets, albeit such rules are largely preliminary guidelines. Hence, there are options for variations and for that the administration as well as the designers and builders are helped with background to accelerate the approval: “fast track to approval”.

The cofferdams adjacent to methanol tanks and handling spaces introduce design challenges:

- Extra space claim in combination with methanol fuel which itself requires more tank volume (factor 2 to 3) for the same mission profile compared to traditional fuels.
- Providing safe access and ventilation of the cofferdams for inspection impacting the arrangement.
- Additional structural weight due to the introduction of extra structural bulkheads and decks.

Hence the question has been raised whether a cofferdam can be replaced by something less consequential for the ship lay-out. Alternative design is an accepted, if not demanded, method to assess solutions for situations that are not covered in the rules or alternatives to prescriptive rules. This methodology is applied in this document to the steel fuel tank for methanol storage.

This document presents a concept HAZID (Hazard Identification) study of a steel structural methanol fuel tank on a ship. The goal of this HAZID is to identify the involved events, consequence effects and likelihood for the base case cofferdam such that alternative cofferdam designs and solutions can be assessed for equivalent safety. This will enable designers and shipowners to innovate in ship design.
The second goal of this document is to identify knowledge gaps required for a quantitative risk analysis of such system and the way forward to incorporate alternative designs in such analysis.

1.3 Revision table

Date	Description	Author	Reviewer	PM	Approver
22 Jan 2025	For external review	REK, BRF	TGL, HDM	DEA	
11 Mar 2025	For internal review	REK, BRF	DTS	DEA	
1 April 2025	Final			DEA	ValidSigned by Ann Delahaye on 2025-04-01 14:17:37

2 Cofferdam Application

2.1 Definition

A cofferdam is an empty space in a ship between two compartments such that the compartments do not share a common boundary. A cofferdam can be arranged horizontally or vertically. A double hull is a special case of cofferdam between one compartment and side shell, bottom or deck.

The goal of a cofferdam is to provide a secondary barrier to prevent:

- Leakage between two compartments,
    - resulting in mixture of two fluids (e.g. fuel and water ballast)
    - resulting in a fire / explosion or toxic hazard.
- Prevent heat transfer between two compartments
    - with two fluids at different containment temperatures
    - in case of a fire.
- Prevent spill (double hull [1] and [2])
    - of a toxic fluid to the environment which endangers human and marine life
    - to prevent environmental pollution.

2.2 Rules and Regulations

Cofferdam requirements are depending on the ship type and navigation area. Different rule sets apply for inland shipping and sea-going vessels. The two international authorities involved are the CESNI (European committee for drawing up standards in the field of inland navigation) and the IMO (Internal Maritime Organisation) respectively. The rules and guidelines in place for low flash point fuels are adopted for methanol:

- CESNI ES-TRIN - CHAPTER 30 Special Provisions Applicable to Craft Equipped with Propulsion or Auxiliary Systems Operating on Fuels with a Flashpoint Equal to or Lower than 55 °C [3].
- IMO IGF Code MSC.391(95) Code of safety for ships using gases or other low-flashpoint fuels [4].
- IMO MSC.1/Circ.1621 (7 December 2020) – Interim Guidelines for the Safety of Ships using Methyl/Ethyl Alcohol as Fuel [5].

Individual class societies and flag states can have additional requirements or interpretations on top of these regulations.

2.3 Fuel Storage

2.3.1 Marine Gas Oil Tank

In the traditional (hydrocarbon) fuel tank arrangement a cofferdam is required between:

- Fuel oil tanks and lubricating oil tanks.
- Compartments intended for liquid hydrocarbons and compartments intended for fresh water such as drinking water, water for propelling machinery and boilers, water for fire-fighting purposes, etc.
- compartments for liquid hydrocarbons and tanks intended for the carriage of liquid foam for fire extinguishing.

Deviation of these requirements are allowed in agreement with the involved authorities and industry solutions consist of increasing the plate thickness of the separating bulkheads, increasing the throat thicknesses of the welds and additional structural testing of the tanks with increased pressure head.

A typical engine room layout using marine hydrocarbon fuel oil including cofferdams is presented in Figure 1. Note that cofferdam requirements with regard to the side shell are dependent on the total volumetric amount of fuel in the vessel.

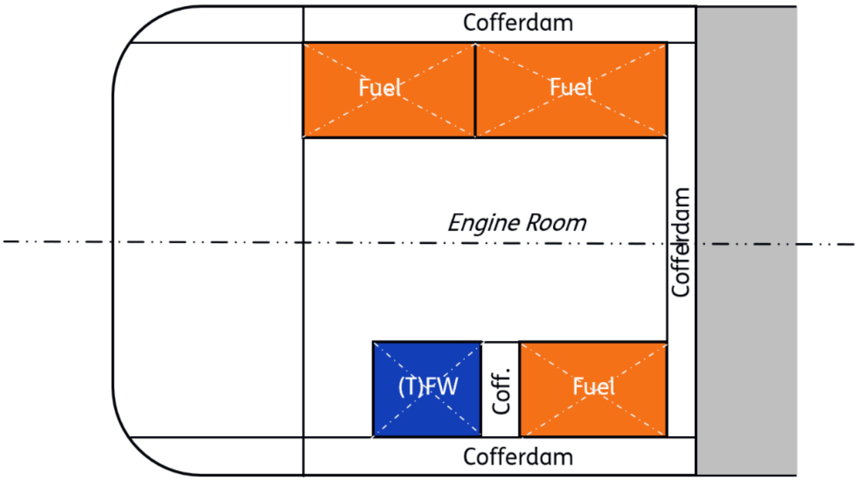

Figure 1 - Schematical Marine Gas Oil engine room layout (top-view)

2.3.2 Methanol Tank

With the introduction of methanol as a fuel, similar requirements for fuel tank separation were defined. The toxic and flammable nature of methanol resulted in additional requirements for cofferdams.

In the context of Methanol Fuels MSC.1/Circ.1621 [5] defines the cofferdam as follows: "*Cofferdam is a structural space surrounding a fuel tank which provides an added layer of gas and liquid tightness protection against external fire, and toxic and flammable vapours between the fuel tank and other areas of the ship.*"

The requirement for cofferdams around methanol fuel tanks is defined in MSC.1/Circ.1621 [5]: *5.3.2 Integral fuel tanks should be surrounded by protective cofferdams, except on those surfaces bound by shell plating below the lowest possible waterline, other fuel tanks containing methyl/ethyl alcohol, or fuel preparation space.*

In practice this means that at additional locations cofferdams are required compared to designs with hydrocarbon (MGO) fuels. In general methanol tanks need to be separated from all other non-methanol compartments by a cofferdam with the exception of the outer shell under the lowest possible water line. This study does not take into account the free-standing tanks (indicated with transparency in Figure 2).

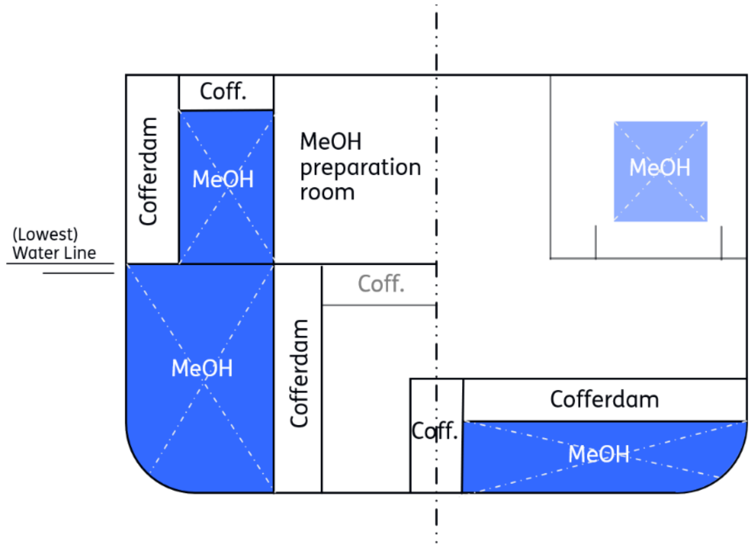

Figure 2 - Cofferdam requirements MeOH Fuel tanks

2.4 Practical Considerations

In the design of a cofferdam structure several practical consideration have to be taken into account. Cofferdams are confined spaces which are kept as small as reasonable possible. Cofferdams cannot be used for any other purpose.

From a design perspective a cofferdam introduces:

- Extra space claim in combination with methanol fuel which itself by itself requires more tank volume (factor 2 to 3) for the same mission profile compared to traditional fuels.
- Additional measures for providing safe access and ventilation of the cofferdams for inspection, impacting the arrangement.
- Increasingly difficult structural details to build (welding, etc.) in case of compact cofferdams.
- Equipment and lay out restrictions to allow for emptying the cofferdam (after a leakage).
- Additional structural weight due to the introduction of extra structural bulkheads and decks.

Access to the cofferdam is required during building of the ship, and maintenance and inspections. The access to the cofferdam should be safe and evacuation in case of an emergency is possible.

Classification rules require a cofferdam to be arranged such that ventilation can be reliably managed and of sufficient size to allow for inspection [6]. “Sufficient size to allow for inspection” is commonly interpreted as a minimum distance of 600 mm between the bulkheads (or decks) of the cofferdam. This excludes the plate stiffeners itself for which a minimum distance of 450 mm is used in the case of traditional fuels. These limits are minimum values. In shipbuilding practice increased access dimensions and norms are used in yard standards and operator requirements for the purpose of safety and ergonomics [7], [8]. Inspection of cofferdams by cameras is approved on a case by case basis. This requires significant additional inspection holes throughout the cofferdam structure which might not be feasible for large vessels containing large (longitudinal) cofferdams.

3 Equivalent Safety

3.1 Definition

This chapter continues the work of GMM 2.0 [9] on equivalent safety and a risk-based approach. A first definition and possibilities of equivalent safety were presented. This report continues with a qualitative assessment. The goal of the approach as will be presented is to serve as a tool common base for "Fast Track to Approval" and Alternative Design procedures.

CESNI [3] and IMO [4] prescribe a risk-based approach to demonstrate that alternative fuels attain a safety level equivalent to the level of conventional hydrocarbon fuels.

Based on the IMO IGF code [4]: "*the safety, reliability and dependability of the systems shall be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery*."

Regulatory bodies allow hydrocarbon based fuels on board of vessels. This implies that the conventional fuels and its vessel designs are considered sufficiently safe. A vessel incorporating methanol as its fuel should be equally safe compared to a conventional fueled system.

An equivalent safety level is obtained by comparing risks defined as the combination of potential harmful events with a probability of occurrence and the consequence of the harmful events. This equivalent safety can be highly dependent on the vessel design under consideration. This report focusses on cofferdam structures around methanol fuel tanks with the goal to identify the involved risk spectrum to present a baseline which can be used in alternative designs to reach equivalent safety.

3.2 Risk Based Approach

Risk-based approaches consist of analyses of probabilities and consequences. In addition to these analyses, the standards and criteria that the risk must meet for acceptance are part of the approach. Figure 3 presents a schematic overview of a risk analysis. Three phases are distinguished:

1. Qualitative analysis consisting of the analysis of functions and elements of the system under consideration; identifying hazards, failure events and consequences.
2. Quantitative analysis which aims at the quantification of the probabilities of failures, consequences.
3. Decision-making in which the results of the former analyses are evaluated against criteria to determine acceptance or formulate mitigation measures. These shall be checked for effectiveness in a similar fashion.

A quantitative analysis is not always possible. In such cases only a qualitative risk analysis will be carried out in a global assessment of the risks involved.

The risk analysis as given in Figure 3 enables a framework to approach alternative designs in a systematic manner. The challenge is to quantify risks, its underlying event likelihoods and consequences. This requires statistical data, test data and expert opinions.
On the side of the decision making a similar set of knowledge is required. The acceptance criteria of a certain risk level needs to be quantified to be able to be used for different designs.

When these likelihoods and consequence effects and risks are available in a common frame work this will enable projects with innovative designs to implement "Fast Track of Approval" principles.

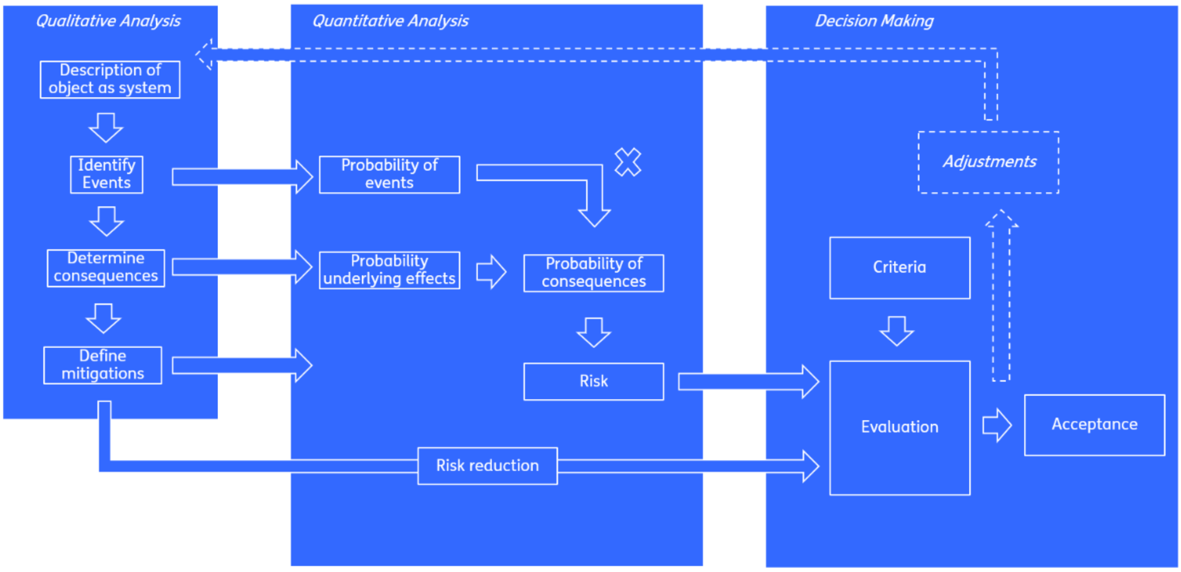

Figure 3 - Risk Analysis schematical overview

3.3 Cofferdam as a Safeguard

The risk-based approach enables the user to define a safety-equivalence for a particular design. Hydrocarbon systems are taken as reference and new solutions shall have equivalent safety. MSC.1/Circ.1621 [5] states for methanol tanks: *Cofferdam is a structural space surrounding a fuel tank which provides an added layer of gas and liquid tightness protection against external fire, and toxic and flammable vapours between the fuel tank and other areas of the ship.*
Taking this as the mitigation, the underlying reasoning is most likely:
A cofferdam adds an extra layer of protection to the events:

- External fire (and heat)
- Leakage
- Spill

A cofferdam provides mitigations against the consequences:

- Toxic vapours
- Flammable vapours

According the principle of equivalent safety, a technical solution which is assessed for the same set of events and consequences as the reference solution and results in similar or lower risks is deemed equally safe. Other, technical innovative solutions could therefore be accepted as alternative design solutions to a cofferdam using a risk-based approach.

In literature multiple risk assessment studies are available for methanol fuelled ships such as [9], [10], [11], [12]. These published studies are aimed at a specific vessel with specific cases. In these assessments the methanol storage tanks are an element (usually of a node) in the risk analysis. Cofferdams are then identified as safeguard for risk mitigation, without much further contemplation about the consequences of a cofferdam or how it shall look like. A qualitative assessment of cofferdams around methanol tanks on board is presented in [13]. Risk assessments for land based storage tanks are available, such as [14] and [15].

4 Methanol Tank Failure

4.1 System Description

The purpose of a methanol fuel tank is to hold and store methanol fuel on board of the vessel. The fuel tanks considered in this study are intended for the fuel consumed during sailing and operations on board.

The tanks can be integral or free-standing tanks. Integral tanks are part of the vessel structure bounded by stiffened bulkheads and decks. Integral tanks are also called structural tanks. The tanks are most commonly executed in marine classified structural steel. Free-standing tanks are loose tanks which can be located throughout the vessel and open deck. These tanks are mounted on a foundation which connects the tank to the vessel. In general free-standing tanks are of smaller volume than integral tanks. This study focusses on uncoated integral tanks.

Fuel tanks are filled via a pipe system from the vessel bunker station to the tank. The vapour above the fluid is normally returned to the bunker provider. The tank content is emptied by a pump-driven pipe system to the fuel treatment space.
Fuel tanks are executed with an ullage pipe and a pressure sensor. A methanol tank is filled to a predefined level with liquid methanol. Current practice on board of vessels sailing on methanol is to apply a blanket gas. Above the methanol liquid the tank is filled with blanket gas, usually a mix of nitrogen with low oxygen content and methanol vapour, held at a slight overpressure, about 102% to 110% of atmospheric pressure [13] controlled by a PV valve.

Venting of the tank is required in case of an overflow situation or a unforeseen pressure rise in the tank. The minimal vent height and location is prescribed by the involved authorities.
The concept HAZID which follows focusses primary on the fuel storage function. Other systems involved in methanol power train are not considered.

4.2 Methanol

Methanol is transparent colourless liquid which is solvable in water and has biodegradable properties. Methanol is considered toxic. The safe Time Weighted Average value is considered to be 200 ppm for an exposure for 8 hr/ day, 40 hr/ week professional life in most countries, and 100 ppm more stringent cases (such as The Netherlands). The Immediate Danger to Life and Health (IDLH) concentration is considered to be 6000 ppm [16]. This is a 15 minutes exposure limit.

Table 4.1 – General properties of methanol [9]

Description	Value / Classification
Name	Methanol
Chemical formula	CH_3OH
Molar mass [kg/kmol]	32.04
Density [kg/m³]	792
Freezing point [°C]	-98
Flash point [ºC]	12
Boiling point [ºC]	64.6
Critical point [°C], [MPa]	239, 8.084
Explosive/Flammable limits in air (v/v%)	6 (LEL/LFL) – 36 (UEL/UFL) 6.7 (LEL/LFL)
Solubility: Methanol in water/ Water in methanol	100%/100%
Flammable vapour above methanol/water mixture	100wt% methanol – 25wt% methanol
Conversion factors	1 ppm = 1.33 mg/m3; 1 mg/m3 = 0.76 ppm

4.3 Concept HAZID

4.3.1 Approach

A HAZID study is a risk identification technique with the goal to identify hazardous events, its consequences and the effects of these consequences on the system under consideration. A HAZID is a qualitative risk assessment in accordance with Figure 3.

The HAZID consists of the following steps:

1. Hazard identification.
2. Risk Analysis and evaluation: likelihood of the event and the severity of its consequences.
3. Risk Mitigation.

The hazardous events and consequences are derived from similar HAZIDs performed for alternative fuels onboard and graded by TNO colleagues. Only hazards affecting the vessel and its crew are considered in this study. Land based incidents such as a crash into a bridge with land based consequences are omitted. For each event the potential consequences and its effects are determined. Each consequence effect is given a gradation according to the matrix in Figure 4 for the Persons on board, the asset under consideration (Ship) and the Environment. Definitions of the scale from Minor to Catastrophic are indicated per category.

	Effects:		
	Persons on board (P)	**Ship (S)**	**Environment (E)**
Minor 1	Minor injury	Local Structural damage	Limited and reversibele damage to sensitive areas and/or species in the immediate vicinity
Localised 2	Single major injury / long-term heath effect	Non-severe ship damage	Localized significant but reversibele damage to sensitive areas and /or species in the immediate vicinity
Major 3	Single fatility or multiple major injuries	Severe damage	Extensive or persistant damage to sensitive areas and/or species
Catastrophic 4	Multiple fatilities	Loss of ship	Irreversible lasting damage to sensitive areas and/or species

Figure 4 - Consequence Effect Matrix

The next step in the HAZID is to determine the likelihood of an event. This can be based on literature sources and expert estimations. These probabilities are part of the risk matrix in Figure 5 in which the likelihoods are presented per column. The combined severity of the consequence effects is divided over the rows. A risk profile follows from this matrix per event.

Medium	Medium	Medium	High	High	High	Catastrophic 4	Severity of consequence
Low	Medium	Medium	Medium	High	High	Major 3	
Low	Low	Low	Medium	Medium	High	Localised 2	
Low	Low	Low	Low	Medium	Medium	Minor 1	
Remote A	Ex. Unlikely B	Very Unlikely C	Unlikely D	Likely E	Very Likely F		
Likelihood							
≤10^{-6} per year	> 10^{-6} to 10^{-5} per year	>10^{-5} to 10^{-4} per year	>10^{-4} to 10^{-3} per year	>10^{-3} to 10^{-2} per year	>10^{-2} per year		

Figure 5 - Risk Matrix

The evaluation of the acceptance of such a risk is based on the level. When the risk is considered low no further actions are required within the risk assessment. Is the risk medium the As Low As Reasonably Practicable (ALARP) principle is applied: take measures if the cost are small compared with the risk they mitigate. This principle is industry practice, see [17], [18]. Events with medium risk are considered of equivalent safety if the same risk evaluation level is obtained for the Marine Gas Oil case. Additional safeguards and mitigation measures can be applied to reduce the risk and improve the safety.

When the risk is considered to be high, additional control measures and safeguards have to be implemented to reduce the probability (likelihood) of the event or to reduce the effects of the consequence. Figure 6 presents the risk acceptance grading applied in this HAZID study in combination with the Risk Matrix of Figure 5.

Low	The level of risk is acceptable
Medium	The level of risk is acceptable, provided that further risk reduction measures are considered not the be practically applicable (ALARP principle)
High	The level of risk is not acceptable and risk control and mitigation measures are required

Figure 6 - Risk Acceptance Grading

4.3.2 HAZID results

The goal of this concept HAZID is to study the potential hazardous events concerned with an integral (structural) methanol fuel storage tank on board of a ship. For this document, a lay-out of a structural, integral methanol fuel tank is taken. Nodes are defined in analogy with a HAZID for a ship or system design.
The resulting inventory of risks and measures can be used to identify the actual role of the cofferdam. Alternative solutions to cofferdams can then be evaluated against the same matrix of events and consequences to demonstrate equivalent safety.

Table 4.2 - Concept HAZID Unmitigated Severities

			Unmitigated Severity				
Category	**Event**	**Consequences**	**P**	**S**	**E**	**Likelihood**	**Risk**
1. Structural	Leakage at flange connection	- MeOH pool in space - Toxic vapour in (confined) space	2	1	1	C	Low
	Leakage at faulty welds	- MeOH pool in space - Mixture with content of tank - Toxic vapour in (confined) space	2	1	1	C	Low
	Leakage at fatigue cracks	- MeOH pool in space - Mixture with content of tank - Toxic vapour in (confined) space	2	1	1	D	Medium
	Leakage at corrosion spots	- MeOH pool in space - Mixture with content of tank - Toxic vapour in (confined) space	1	1	1	D	Low
2. Equipment	Failing tank level indicator	- Possible contact between human and MeOH when opening an assumed empty tank - Tank overflow during bunkering	3	1	1	C	Medium
	Electrical system blackout	- No read-out of tank-level indicator - Fuel pump stops - Pressure monitoring stops - Gas detection system not operational - No control of electric valves	1	1	1	D	Low
	Vent point (mast) is clogged	- Impossible to vent MeOH in case of overpressure	3	2	2	B	Medium
3. Location / Environment	Collision under waterline resulting in hull rupture	- Flooding of tank - Loss of Containment of MeOH result in spill	1	3	2	B	Medium
	Collision above waterline resulting in hull rupture	- Loss of Containment of MeOH result in spill - Toxic vapour - Ignition of MeOH vapour in tank	3	2	2	C	Medium
	Grounding	(see collision under waterline resulting in hull rupture)	2	2	2	C	Low
	Sinking	- Flooding of tank - Structural overloading due to water pressure resulting in rupture leakage	2	3	1	D	Medium
	(External) Fire in adjacent compartment	- Increase temperature in MeOH tank - Overpressure due to temperature rise resulting in uncontrolled venting	2	3	1	D	Medium
	(External) Fire on deck	- Increase temperature in MeOH tank - Uncontrolled vapour venting	2	3	1	D	Medium
	Ambient and sun resulting in high ambient temperature	- Increase temperature in MeOH tank - Uncontrolled vapour venting	1	1	1	C	Low
	Very low ambient temperature	- Ice blocking the venting resulting in overpressure	1	1	1	C	Low
	Rain	- Water ingress through vent mast resulting in rain water mixing with methanol	1	1	1	F	Medium
	High wind conditions	- High vessel movement resulting in heavy MeOH movements and venting	1	1	1	D	Low
	Lightening strike	- Power blackout	2	2	1	B	Low
4. Materials	Ignition of explosive cloud from tank vent	- Fire at the tank vent outlet	2	2	2	B	Low
	Toxic vapour at tank vent	- Toxic cloud at the vessel	2	1	1	E	Medium
	Corrosive MeOH in stainless steel and aluminium piping	- Extensive corrosion in aluminium piping and engine	1	3	1	E	High
5. Operations	Collision with equipment (crane hook, suction head on a dredger, ROV, etc.)	- Loss of containment (LOC) of MeOH (see collision above and below waterline	2	2	1	D	Medium
	Falling or shifting objects / cargo resulting in rupture of tank boundary	- Tank bulkhead failure resulting in MeOH spill in compartment - Toxic vapour in space - Flamable vapour in space	3	2	2	C	Medium
	Falling or shifting object resulting in damage of pipe connection	(see leakage at flange connection)	2	1	1	C	Low
	Opening wrong access manhole (human failure)	- Direct exposure of persons to MeOH	3	1	1	E	Medium
	Welding work at filled tank deck or bulkhead	- Local heat introduction resulting in overpressure and uncontrolled venting	1	1	1	C	Low

In the first step the system is considered without safeguards to identify the possible hazardous events, consequences and its effects (see Table 4.2). The complete concept HAZID results can be found in Appendix A. In the HAZID a set of 26 hazardous events are assessed. Events with low risks are not considered further in the assessment as they are deemed sufficiently safe.

Table 4.3 - Medium and high risk events with mitigation measures

				Mitigated Severity				Comments
Category	**Event**	**Consequences**	**Safeguards**	**P**	**S**	**E**	**Risk**	
1. Structural	Leakage at fatigue cracks	- MeOH pool in space - Mixture with content of tank - Toxic vapour in (confined) space	- **Cofferdam** - weld inspection during new-built (NDT) - Extra inspections during survey	1	1	1	Low	
2. Equipment	Failing tank level indicator	- Possible contact between human and MeOH when opening an assumed empty tank - Tank overflow during bunkering	- Procedures before entering tank - Entering confined tank space with breathing apparatus - Overflow tank - Mechanical Overflow detection	1	1	1	Low	no effect of cofferdam
	Vent point (mast) is clogged	- Impossible to vent MeOH in case of overpressure	- Regular cleaning - Regular inspection (before bunkering) - Tank is designed for overpressure	2	2	2	Low	no effect of cofferdam
3. Location / Environment	Collision under waterline resulting in hull rupture	- Flooding of tank - Loss of Containment of MeOH result in spill	- fuel tank rupture does not result in loss of ship (damage stability)	1	3	2	Medium	- Methanol disolves in water - Considered ALARP in current regulations
	Collision above waterline resulting in hull rupture	- Loss of Containment of MeOH result in spill - Toxic vapour - Ignition of MeOH vapour in tank	- **Cofferdam** / double hull	1	2	1	Low	Assuming no double breach takes place
	Sinking	- Flooding of tank - Structural overloading due to water pressure resulting in rupture leakage	- Methanol tank designed for flooded condition - Methanol tank vent closes under water (fully closed tank)	2	3	2	Medium	Considered ALARP
	(External) Fire in adjacent compartment	- Increase temperature in MeOH tank - Overpressure due to temperature rise resulting in uncontrolled venting	- **Cofferdam** - fire / heat insulation - fire fighting installation	2	2	1	Medium	
	(External) Fire on deck	- Increase temperature in MeOH tank - Uncontrolled vapour venting	- **Horizontal cofferdam** - Fire fighting	1	2	1	Medium	
	Rain	- Water ingress through vent mast resulting in rain water mixing with methanol	- Water catching / vent protection	1	1	1	Low	Methanol dissolves in water Possible contamination of methanol
4. Materials	Toxic vapour at tank vent	- Toxic cloud at the vessel	- no Crew escape routes or walkways in close proximity - venting position reasonably far from deck	1	1	1	Low	
	Corrosive MeOH in stainless steel and aluminium piping	- Extensive corrosion in aluminium piping and engine parts	- Design engine system without sensitive materials	1	2	1	Medium	Requires additional research
5. Operations	Collision with equipment (crane hook, suction head on a dredger, ROV, etc.)	- Loss of containment (LOC) of MeOH (see collision above and below waterline	- Cofferdam - Design restrictions for mission equipment - extra shell thickness at potential hit areas	2	2	1	Medium	
	Falling or shifting objects / cargo resulting in rupture of tank boundary	- Tank bulkhead failure resulting in MeOH spill in compartment - Toxic vapour in space - Flamable vapour in space	- **Cofferdam** - Additional plate thickness / stiffeneres	1	1	1	Low	
	Opening wrong access manhole (human failure)	- Direct exposure of persons to MeOH	- Procedures before entering tank - Training - Entering confined tank space with breathing apparatus	1	1	1	Low	

As stated in section 3.3 the cofferdam is a safeguard for a set of events. When analysing Table 4.2 and Table 4.3 it can be concluded that cofferdams act as a mitigation against:

- Leakage resulting in uncontrolled liquid methanol resulting in flammable vapour conditions.
- Leakage resulting in uncontrolled liquid methanol resulting in toxic vapour conditions.
- Leakage resulting in mixture with adjacent tank contents (e.g. potable water).
- A barrier against direct collision/ dropped objects resulting in tank rupture.
- External heat barrier (minor).
- Direct access to methanol tank by personnel .

Other hazardous events for methanol tanks on board such as a clogged vent point or corrosion effects of methanol in piping systems are not mitigated by a cofferdam. Figure 7 presents an visualization of the events (red) and consequence (orange) effects resulting from the HAZID analysis of a methanol storage tank in which a cofferdam is used as a safeguard:

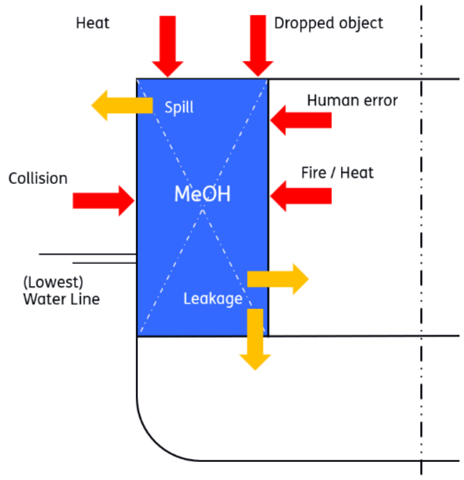

Figure 7 – Methanol Tank Cofferdam relevant events and consequences

This study shows that the appliance of a cofferdam is ALARP in case of a methanol fuel tank. This means that the cofferdam qualifies as reasonably safe solution. However, this does not disqualify alternative solutions. These alternative solutions are available and able to obtain similar ALARP status which enables them to be safe alternatives to cofferdam structures. Additional HAZID studies of those alternatives are recommended to be added to this report.

4.3.3 Comparison with MGO Tank

The safeguards from the HAZID study which involves a cofferdam can be compared for a methanol fuel tank and a MGO tank. In Table 4.4 the following differences arise between MGO and methanol tank cofferdam purposes:

- Toxicity of (vaporized) methanol.
- Flammability of (vaporized) methanol to a lesser degree.
- MGO spill is considered very harmful for the environment (this is covered in MARPOL and SOLAS regulations [1], [2]). Methanol is soluble in water which reduces the direct impact on the environment.
- Human error such as removing a wrong manhole can lead to direct tank access and as such direct contact with methanol.

Table 4.4 - Comparison Methanol and MGO tank cofferdam

Consequence	Cofferdam Purpose	MGO	MeOH
Pressure built up by external heat (adjacent space)	Limit heat transfer to tank	X	X
Leakage (to adjacent space)	Prevent toxic vapour in compartment (Barrier and detection)		X
Leakage (to adjacent space)	Prevent flammable vapour in compartment (Barrier and detection)	/	X
Leakage to adjacent tank (water)	No shared boundary (Barrier and detection)	X	X
Dropped / Shifting object	Prevent Structural Damage of tank (Barrier)	X	X
Collision under waterline	Prevent Spill resulting in Environmental Damage (Barrier)	X	
Collision above waterline	Prevent Spill resulting in Environmental Damage (Barrier)	X	/
Collision above waterline	Prevent Toxic cloud / vapour (Barrier / detection)		X
Direct access to tank (human error)	No direct access to tank		X

4.4 Risk Mitigation

The risk of an hazardous event can be lowered by reducing the likelihood of the event or by mitigating the consequence effects. Alternatives to cofferdams need to provide a solution which has equivalent safety. Based on the HAZID study the following concept inventory of (a combination) of solutions would mitigate such risks:

Leakage Control:

- Construction foam based solutions[1].
- Detection of methanol by adding odour and colour (negative impact on fuel cell systems).
- Gas detection.
- Overpressure system and pressure measurement (e.g. nitrogen blanket).
- Additional requirements tank weld (NDT, etc.).
- No physical boundary between methanol tank and other tanks (e.g. Potable water).
- Methanol is soluble in water, spills underwater or flooding has less risk and may be accepted.

Structural Integrity:

- Thickness increase of bulkhead and increase of weld specification (in line with MGO cofferdam equivalent design such as [19]). In current rules tank bulkheads are designed for sea water flooding which provides an approximate safety margin of 30% due to density difference of methanol and sea water.
- Additional design load case for falling/ shifting object collision.

Heat and fire:

- Fluid/ gas tight foam based solutions for insulation.
- Traditional insulation options (such as A60).
- Additional sprinklers to provide cooling (somewhat similar to galley roller shutter solutions).

Inspection and Maintenance:

- Inspection by camera and drone technology in case of limited access.
- Training and awareness.
- Only enter confined spaces and tanks with correct equipment (breathing apparatus, gas detection, etc.). This will result in larger access requirements.

Cofferdams itself are confined spaces which have their own inherent risk profile.
Limited space to evacuate, possibility to contain toxic or flammable vapours and obstructed movement and sight need to be taken into account when evaluating alternative options to cofferdams.

[1] Foam based solutions might increase difficulty of inspection and leakage detection itself.

4.5 Knowledge Gaps

The next step in the risk analysis would be a quantitative analysis of the involved likelihood and consequences. This is pivotal to determine the effect of mitigation measures in alternative solutions of cofferdams such as listed in 4.4.
There are techniques available for calculating the probabilities such as Event Tree Analysis (ETA), Fault Tree Analysis (FTA), or Bayesian Belief Networks analysis (BBN). These methods require the probabilities of the underlying events. These events can be obtained by literature, testing, data analysis or expert opinion. For the use of methanol tanks on board ships limited data is available. The data from new-built and conversion projects is limited and the vessels are in the beginning of the operational life.

Incident data on board of vessels is not stored in a publicly accessible database. Such a database would enable designers, classification societies and operators to perform a quantitative risk analysis from the same acknowledged starting point. In case of incidents with methanol one have to be careful to compare the situations with traditional fuels since repairs of the fuel systems are not always recorded and have less risk.

Section 4.3.2 presents the medium consequence effects involving methanol vapour (either as toxic or flammable component in the event). Current research in GMM3-WP1 consists of testing and study the vapour behaviour of methanol in confined non-ventilated and ventilated compartments. This research will produce data to estimate the risk of a pool of methanol. A ventilated room could potentially be beneficial for lowering the toxic concentration but introducing more risk for ignition by adding oxygen.

An inventory of the incidents with cofferdams during both the building as the operation of the ship would give insight in the risk profile introduced by cofferdams. These additional risks need to be taken into account when alternative solutions are considered.

When removing cofferdams local vulnerable points such as manholes may need to be identified to be mitigated in alternative ways, e.g. by an additional cover.

5 Conclusion

5.1 Risk-based approach

A concept HAZID study of a steel structural methanol fuel tank on board is presented. The goal of this HAZID is to identify the involved events, consequence effects and likelihood such that alternative cofferdam designs and solutions can be assessed for equivalent safety. The concept HAZID focussed primary on the fuel storage function. Other systems involved in methanol power train are not considered.

In terms of risk analysis a cofferdam is a safeguard against consequence effects of an hazardous event. When compared to MGO (hydrocarbon) fuel tank cofferdam the methanol tank cofferdam adds protection against:

- Toxicity of (vaporized) methanol.
- Flammability of (vaporized) methanol to a lesser degree.
- Methanol spill overboard, however methanol is solvable in water which reduces the direct impact of the spill compared with traditional fuels.
- Human error such as removing a wrong manhole can lead to direct tank access and as such direct contact with methanol.

Alternative solutions to cofferdams should provide equivalent risk mitigation. In order to determine this equivalent risk and provide efficient solutions a quantitative analysis needs to be performed. A quantitative analysis requires the probabilities of the underlying events. These events can be obtained by literature, testing, data analysis or expert opinion. For the use of methanol tanks on board ships limited data is available.

This study shows that the appliance of a cofferdam is ALARP in case of a methanol fuel tank. This means that the cofferdam qualifies as reasonably safe solution. However, this does not exclude alternative solutions. These solutions are available and able to obtain similar ALARP status which enables them to be safe alternatives to cofferdam structures. Additional HAZID studies of those alternatives are recommended to be added to this report.

Cofferdams by themselves are confined spaces which have their own inherent risk profile. Practical limitations in design, building, operation and inspection result in limited space to evacuate, the possibility to have toxic or flammable vapours in a confined space and obstructed sight need to be taken into account when evaluating alternative options to cofferdams.

5.2 Recommendations

The concept HAZID has identified the hazardous events for a structural methanol tank. Based on the HAZID the following recommendations are made:

- Further refinement in events, consequence effects and alternative mitigation measures of this HAZID is recommended such that it can serve as a starting point for specific case risk analysis studies.

- Extend the current HAZID for alternative solutions to show equivalent ALARP status.

- In order to test the validity of the HAZID for a more specific case it is recommended to perform a case study in which the concept HAZID study can be used.

- Publicly accessible database of incident data on board of vessels. Such a database would enable designers, classification societies and operators to perform a quantitative risk analysis from the same acknowledged starting point.

- Incorporate test results of vapour tests and derive probabilities of forming of toxic / flammable vapour.

- Perform additional research on detection of methanol by adding a chemical compound with odour and / or colour (taking into account fuel cell operations).

- An inventory of the incidents with cofferdams during both the building as the operation of the ship would give insight in the risk profile introduced by cofferdams. These additional risks need to be taken into account when alternative solutions are considered.

- Investigate and assess local solutions for the vulnerable points (e.g. additional space around manholes) or ways to detect methanol leakages before they pose a risk, e.g. adding an odour.

References

[1] IMO, "MARPOL Annex I - Construction Requirements for Oil Tankers (Double Hulls)," IMO, 1993.

[2] International Convention for the Safety of Life at Sea (SOLAS), "SOLAS Chapter II-1 Construction - Structure, subdivision and stability, machinery and electrical installations Reg. 12," IMO, 2004.

[3] CESNI, "ES-TRIN - European Standard laying down Technical Requirements for Inland Navigation Vessels"," CESNI, 2021/01.

[4] IMO, "IGF Code MSC.391(95) Code of safety for ships using gases or other low-flashpoint fuels," IMO, London, England, 2015.

[5] IMO, "MSC.1/Circ.1621 Interim Guidelines for the Safety of Ships using Methyl/Ethyl Alcohol as Fuel," IMO, London, England, 2020.

[6] Bureau Veritas Marine & Offshore, NR670 Methanol & Ethanol Fuelled Ships, Paris, France: Bureau Veritas, 2022.

[7] O. B. J. Ola Stråby, "FT.2023.169 - Maersk recommended minimum cofferdam size for concept design," Maersk FT (NA), 02 October 2023.

[8] Witherby, Pocket Safety Guide Confined Spaces, ISBN 13: 978 1 905331 81 9, Livingston, Scotland, UK: Witherby Publishing Group Ltd, 2010.

[9] C. H.-D. A. V. N. W. A. F. M.L. Deul, "WP1 Development of safety solutions," Green Maritime Methanol 2.0, Delft, 2023.

[10] J. B. Joanne Ellis, "D4.1b Hazard Identification Study for the M/S Jupiter Methanol - Conversion Design," SUMMETH – Sustainable Marine Methanol, 2018.

[11] C-Job , "21.516 Doc. Nr 950-106 - Design and Safety Statement - Design Description," C-Job / Rijkswaterstaat, Hoofddorp, 2022 (Preliminary).

[12] GMM consortium partners, "Public Final Report: WP 5 - System Design for Short Sea Shipping," TKI Martime & Netherlands Ministry of Economic Affairs, 2020.

[13] O. Stråby, "Notes on cofferdam protection requirement for methanol fuel tanks," Maersk, 07 Dec 2023.

[14] K. G. I. M. M. M. A. Ehsan Ramezanifar, "Risk assessment of methanol storage tank fire accident using hybrid FTA-SPA," *PLoS One,* vol. 3, no. 18, 2023.

[15] E. Medina, "Methanol Hazards & Safeguards Lessons Learned From the Global Supply Chain," ASSE, Park Ridge (IL), USA, 2014.

[16] Center for Disease and Control Prevention, "Methyl alcohol - Immediate Dangerous to Life and Health Concentrations (IDLH)," NIOSH, 15 9 2016. [Online]. Available: https://www.cdc.gov/niosh/idlh/67561.html. [Accessed 2024].

[17] ABS, "Guidenance notes on risk assessment applications for the marine and offshore industries," American Bureau of Shipping, Spring (Texas), USA, 2020.

[18] IACS, "Record No. 127 (Rev. 1) A Guide to Risk Assessment in Ship Operations," IACS, London, England, 2021.

[19] Bureau Veritas Offshore & Marine, "NR467 Steel Ships - Part B Hull and Stability," Bureau Veritas, Paris (France), 2025.

[20] A. T. C. Guedes Soaras, "Risk Assessment in Maritime Transportation," *Reliability Engineering and Safety,* no. 74, pp. 299-309, 2001.

Appendix A HAZID table

			Unmitigated Severity						Mitigated Severity				Comments
Category	Event	Consequences	P	S	E	Likelihood	Risk	Safeguards	P	S	E	Risk	
1. Structural	Leakage at flange connection	- MeOH pool in space - Toxic vapour in (confined) space	2	1	1	C	Low	- **Cofferdam** - weld inspection during new-built (NDT) - Extra inspections during survey	1	1	1	Low	depends on location of flange
	Leakage at faulty welds	- MeOH pool in space - Mixture with content of tank - Toxic vapour in (confined) space	2	1	1	C	Low	- **Cofferdam** - weld inspection during new-built (NDT) - Additional weld throat thickness - Extra inspections during survey	1	1	1	Low	Potential toxic vapour in cofferdam
	Leakage at fatigue cracks	- MeOH pool in space - Mixture with content of tank - Toxic vapour in (confined) space	2	1	1	D	Medium	- **Cofferdam** - weld inspection during new-built (NDT) - Extra inspections during survey	1	1	1	Low	
	Leakage at corrosion spots	- MeOH pool in space - Mixture with content of tank - Toxic vapour in (confined) space	1	1	1	D	Low	- **Cofferdam** - weld inspection during new-built (NDT) - Extra inspections during survey	1	1	1	Low	
2. Equipment	Failing tank level indicator	- Possible contact between human and MeOH when opening an assumed empty tank - Tank overflow during bunkering	3	1	1	C	Medium	- Procedures before entering tank - Entering confined tank space with breathing apparatus - Overflow tank - Mechanical Overflow detection	1	1	1	Low	
	Electrical system blackout	- No read-out of tank-level indicator - Fuel pump stops - Pressure monitoring stops - Gas detection system not operational - No control of electric valves	1	1	1	D	Low	- backup power for safe termination of fuel system - crew training and procedures - no access to fuel tanks during blackout	1	1	1	Low	
	Vent point (mast) is clogged	- Impossible to vent MeOH in case of overpressure	3	2	2	B	Medium	- Regular cleaning - Regular inspection (before bunkering)	2	2	2	Low	
3. Location / Environment	Collision under waterline resulting in hull rupture	- Flooding of tank - Loss of Containment of MeOH result in spill	1	3	2	B	Medium	- fuel tank rupture does not result in loss of ship (damage stability)	1	3	2	Medium	- Methanol disolves in water - Considered ALARP in current regulations
	Collision above waterline resulting in hull rupture	- Loss of Containment of MeOH result in spill - Toxic vapour - Ignition of MeOH vapour in tank	3	2	2	C	Medium	- **Cofferdam** / double hull	1	2	1	Low	Assuming no double breach takes place
	Grounding	(see collision under waterline resulting in hull rupture)	2	2	2	C	Low	(see collision under waterline resulting in hull rupture)	2	2	2	Low	
	Sinking	- Flooding of tank - Structural overloading due to water pressure resulting in rupture leakage	2	3	3	D	Medium	- Methanol tank designed for flooded condition - Methanol tank vent closes under water (fully closed tank)	2	3	2	Medium	Considered ALARP
	(External) Fire in adjacent compartment	- Increase temperature in MeOH tank - Overpressure due to temperature rise resulting in uncontrolled venting	2	3	1	D	Medium	- **Cofferdam** - fire / heat insulation - fire fighting installation	2	2	1	Medium	
	(External) Fire on deck	- Increase temperature in MeOH tank - Uncontrolled vapour venting	2	3	1	D	Medium	- **Horizontal cofferdam** - Fire fighting	1	2	1	Medium	
	Ambient and sun resulting in high ambient temperature	- Increase temperature in MeOH tank - Uncontrolled vapour venting	1	1	1	C	Low	- **Horizontal cofferdam**				Low	Highly dependent on sailing area
	Very low ambient temperature	- Ice blocking the venting resulting in overpressure	1	1	1	C	Low	- Heat tracing below 12 degrees celcius on outlet	1	1	1	Low	Highly dependent on sailing area
	Rain	- Water ingress through vent mast resulting in rain water mixing with methanol	1	1	1	F	Medium	- Water catching / vent protection	1	1	1	Low	Methanol dissolves in water Possible contamination of methanol
	High wind conditions	- High vessel movement resulting in heavy MeOH movements and venting	1	1	1	D	Low	- Crew training and awareness	1	1	1	Low	
	Lightening strike	- Power blackout	2	2	1	B	Low	- Vessel electrical system is grounded	1	1	1	Low	

4. Materials	Ignition of explosive cloud from tank vent	- Fire at the tank vent outlet	2	2	2	B	Low	- prevent ignition source (EX equipment)	1	1	1	Low	
	Toxic vapour at tank vent	- Toxic cloud at the vessel	2	1	1	E	Medium	- no Crew escape routes or walkways in close proximity - venting position reasonably far from deck	1	1	1	Low	
	Corrosive MeOH in stainless steel and aluminium piping	- Extensive corrosion in aluminium piping and engine parts	1	3	1	E	High	- Design engine system without sensitive materials	1	2	1	Medium	Requires additional research
5. Operations	Collision with equipment (crane hook, suction head on a dredger, ROV, etc.)	- Loss of containment (LOC) of MeOH (see collision above and below waterline	2	2	1	D	Medium	- **Cofferdam** - Design restrictions for mission equipment - extra shell thickness at potential hit areas	2	2	1	Medium	
	Falling or shifting objects / cargo resulting in rupture of tank boundary	- Tank bulkhead failure resulting in MeOH spill in compartment - Toxic vapour in space - Flamable vapour in space	3	2	2	C	Medium	- **Cofferdam** - Additional plate thickness / stiffeneres	1	1	1	Low	
	Falling or shifting object resulting in damage of pipe connection	(see leakage at flange connection)	2	1	1	C	Low	- Crew procedure and awareness	2	1	1	Low	Pending flange position
	Opening wrong access manhole (human failure)	- Direct exposure of persons to MeOH	3	1	1	E	Medium	- Procedures before entering tank - Training - Entering confined tank space with breathing apparatus	1	1	1	Low	
	Welding work at filled tank deck or bulkhead	- Local heat introduction resulting in overpressure and uncontrolled venting	1	1	1	C	Low	- Work permits & Toolbox meetings - Crew awareness training	1	1	1	Low	

	Effects:		
	Persons on board (P)	**Ship (S)**	**Environment (E)**
Minor 1	Minor injury	Local Structural damage	Limited and reversibele damage to sensitive areas and/or species in the immediate vicinity
Localised 2	Single major injury / long-term heath effect	Non-severe ship damage	Localized significant but reversibele damage to sensitive areas and /or species in the immediate vicinity
Major 3	Single fatility or multiple major injuries	Severe damage	Extensive or persistant damage to sensitive areas and/or species
Catastrophic 4	Multiple fatilities	Loss of ship	Irreversible lasting damage to sensitive areas and/or species

Medium	**Medium**	**Medium**	**High**	**High**	**High**	Catastrophic 4	Severity of consequence
Low	**Medium**	**Medium**	**Medium**	**High**	**High**	Major 3	
Low	**Low**	**Low**	**Medium**	**Medium**	**High**	Localised 2	
Low	**Low**	**Low**	**Low**	**Medium**	**Medium**	Minor 1	
Remote A	Ex. Unlikely B	Very Unlikely C	Unlikely D	Likely E	Very Likely F		
Likelihood							
Could Happen in Industry	Reported	Has occurred at least once in Company Fleet	Has occurred several times in Company Fleet	Happens several times/y in Company Fleet	Happens several times/y on Ship		
$\leq 10^{-6}$ per year	$> 10^{-6}$ to 10^{-5} per year	$>10^{-5}$ to 10^{-4} per year	$>10^{-4}$ to 10^{-3} per year	$>10^{-3}$ to 10^{-2} per year	$>10^{-2}$ per year		

Low	The level of risk is acceptable
Medium	The level of risk is acceptable, provided that further risk reduction measures are considered not the be practically applicable (ALARP principle)
High	The level of risk is not acceptable and risk control and mitigation measures are required