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REVISION HISTORY

A record of revisions and amendments to this document is given below:

Rev.	Date	Reason for amendments	Section changes from previous version
1	30-03-2023	Document Issued	

Abbreviations

ADR	Agreement concerning the International Carriage of Dangerous Goods by Road
ALARP	As Low As Reasonably Practicable
CSP	Cryogenic Spillage Protection
ERC	Emergency Release Coupling
ERS	Emergency Release System
ESD	Emergency Shutdown
F&G	Fire and Gas
FMEA	Failure mode and effects analysis
HAZID	Hazard Identification
HSE	Health and Safety Executive
IACS	International Association of Classification Societies
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF	International Code of Safety for Ships using Gases or other Low flashpoint Fuels
IMDG	International Maritime Dangerous Goods
ISO	International Organization for Standardization
LFL	Lower Flammable Limit
LNG	Liquified Natural Gas
LR	Lloyd's Register
MAE	Major Accident Event
PPE	Personal Protective Equipment
SIMOPS	Simultaneous Operations
SOLAS	Safety of Life at Sea
STCW	Standards of Training, Certification and Watchkeeping for Seafarers
TTS	Truck-To-Ship
QRA	Quantitative Risk Assessment
VCE	Vapour Cloud Explosion

1. Introduction

1.1. Background

The shipping industry currently emits 3% of all the greenhouse gases in the world. Therefore, it is more than relevant that the shipping industry and the port authorities start to invest in decarbonisation, searching for the implementation of zero emission technologies. Today, there are quite a lot of obstacles in order to realise a full-scale use of zero emissions fuels on board of the ships and vessels. In order to tackle some of these obstacles, the ISHY project will investigate the following working fields:

- testing of the effectiveness of the low carbon propulsion technologies
- demonstrating the feasibility of H2 bunkering-facilities in a port
- prepare tools to support the transition to low-carbon propulsion systems for both retrofitting and building of new ships

To support the initiatives on alternative, low and zero-carbon fuels for the maritime industry, Work Package D1.10.1 was to develop a guidance document related to safe use of gaseous and/or liquefied hydrogen.

1.2. Objectives

The objective of this report is to provide guidance on the safe use on the safe use of gaseous and / or liquefied hydrogen to ensure high levels of safety, integrity and reliability are maintained within the shipping industry.

1.3. Scope of Work

This report provides the consolidation of various relevant regulations, guidelines, codes and standards applicable to the use of hydrogen.

2. Applicable Regulations, Codes, Standards and Guidelines

There are many documents and references available related to the use of hydrogen onboard ships, including: rules from classification societies, codes, standards, guidelines, checklists, technical specifications, some of these have been summarised in this chapter.

It is noted that new regulations and guidelines will be published which will incorporate new developments, experience, know-how and industry practice. It is known that organisations are revising and planning to revise some of these standards and guidelines. Hence, this report should be considered as a starting point to build upon and maintain up to date.

2.1. Regulation

Seveso III-RL - Seveso-III-Directive (2012/18/EU) [1]

This Directive lays down rules for the prevention of major accidents which involve dangerous substances, and the limitation of their consequences for human health and the environment, with a view to ensuring a high level of protection throughout the Union in a consistent and effective manner.

According to this directive, the safety report is required to demonstrate:

1) major-accident prevention policy and a safety management system have been implemented,
2) possible major-accident scenarios have been identified and prevention measures have been taken,
3) adequate safety and reliability have been taken into account in the design, construction, operation and maintenance, and
4) internal emergency plans have been drawn up.

The safety report shall be produced in accordance with:

- *Article 10 Safety report*
- *Annex II Minimum data and information to be considered in the safety report referred to in Article 10*
- *Annex III Information referred to in Article 8(5) and Article 10 on the safety management system and the organisation of the establishment with a view to the prevention of major accidents*

The emergency plan shall be prepared in accordance with:

- *Article 12 Emergency plans*
- *Data and information to be included in the emergency plans referred to in Article 12*

(https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0018)

MARPOL - International Convention for the Prevention of Pollution from Ships [2]

The MARPOL is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. The Convention includes regulations aimed at preventing and minimizing, both accidental and operational, pollution from ships.

SOLAS - International Convention for the Safety of Life at Sea [3]

The SOLAS agreement is an international treaty on safety at sea and has been ratified by almost all states and is therefore also national law. It is generally regarded as the most important of all international agreements on the safety of (merchant) ships. SOLAS requires flag states to ensure that their ships meet minimum safety standards in design, equipment and operation.

The following sections are important:

Chapter II-1, Part G - Ships using low-flashpoint fuels, Regulation 57 - Requirements for ships using low-flash point fuels: Except as provided in regulations 56.4 and 56.5, ships using low-flashpoint fuels shall comply with the requirements of the IGF Code

- *Chapter II-2, Part B - Prevention of fire and explosion*
- *Chapter VII Carriage of dangerous goods, Part C - Construction and equipment of ships carrying liquefied gases in bulk*

2.2. Codes and Standards

IGF - International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels [4]

The purpose of IGF Code is to provide an international standard for ships using low-flashpoint fuel, other than ships covered by the IGC Code.

In terms of equipment and bunkering process, the IGF Code is applicable to the recipient ship, i.e. a ship using LNG as fuel, it is considered a good basis for other low flash-point fuels.

The general requirements for risk assessment are in:

- *Part A, 4.2 Risk assessment*

There are requirements for ships using natural gas as fuel (including bunkering in Section 8):

- *Part A-1 - Specific Requirements for Ships Using Natural Gas as Fuel*

IGC - International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk [5]

The IGC Code applies to all seagoing vessels transporting Liquefied Gases in international traffic. This Code applies to ships regardless of their size, including those of less than 500 gross tonnage, engaged in the carriage of liquefied gases having a vapour pressure exceeding 0.28 MPa absolute at a temperature of 37.8°C and other products when carried in bulk. This includes both gas tankers and bunker ships.

IMDG - International Maritime Dangerous Goods [6]

The IMDG Code regulates the stowage and packing regulations, containerized sea transport and in particular the separation of dangerous goods. The IMDG Code does not contain any requirements for ship fuels and therefore no direct requirements for the use of low flash-point fuels.

ISO 31000 Risk management [11]

This document provides guidelines on managing risk faced by organizations. This document provides a common approach to managing any type of risk and is not industry or sector specific. This document can be used throughout the life of the organization and can be applied to any activity, including decision-making at all levels. The risk management framework and process are in Section 5 and Section 6.

IEC 60079-10-1 Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres [13]

This document is concerned with the classification of areas where flammable gas or vapour hazards may arise and may then be used as a basis to support the proper design, construction, operation and maintenance of equipment for use in hazardous areas. It is intended to be applied where there may be an ignition hazard due to the presence of flammable gas or vapour.

The safety zone will normally be inside the monitoring/security area and shall encompass hazardous zones defined by IEC 60079-10-1

Hazardous Zone is any three-dimensional envelope in which a flammable and/or explosive atmosphere may occur in quantities such as to require special precautions to protect the safety of workers, third-party personnel and material. Special precautions and measures for construction, installation and use of electrical apparatus should be followed, as given in IEC EN 60079 -10-1.

ISO/TC 197 Hydrogen technologies [7]

The scope of the technical committee is to standardise systems and equipment used for the production, transport, measurement and use of hydrogen. It shall cover fuelling station equipment such as hoses, fittings and safety considerations.

ISO 19880 Gaseous hydrogen - Fuelling stations [8]

This standard covers the design, installation, commissioning, operation, inspection and maintenance requirements for the safe operation of gaseous hydrogen refuelling stations. While its focus is on road vehicles it has some applicable for marine applications.

ISO/TR 15916:2015 Basic considerations for the safety of hydrogen systems [9]

This technical report is intended to provide information on the properties of gaseous and liquid hydrogen and its associated hazards and risks.

DRAFT ISO 24132 Ships and marine technology — Design and testing of marine transfer arms for liquefied hydrogen [10]

This standard is still underdevelopment and is intended to provide technical guidance and safety requirements for liquified hydrogen marine transfer arms, covering design, minimum safety requirements, inspection and testing procedures. It shall primarily focus on MLAs intended for use at onshore LH2 terminals handling LH2 carriers. While also covering the minimum requirements for safe LH2 transfer between ship and shore.

2.3. Guidelines

The Compressed Gas Association (CGA)

The CGA develops standards and promotes safety standards in the industrial, medical, and food gases industry, and has some publications that could be useful for marine applications, further information can be found at **www.cganet.com**.

3. Hazards

A hazard is defined as a potential source of harm. The hazard, or danger, is intrinsic to the product.

Hydrogen is listed as a named dangerous substance in entry 15 of Annex I Part 2 to the Seveso III Directive **[1].** All establishments which hold at least 5 tonnes of it (less if other dangerous substances are also present) fall under the scope of the Seveso III Directive and, amongst others, need to establish a major accident prevention policy. In addition, operators of upper tier establishments holding more than 50 tonnes of H_2 need to establish, amongst others, a safety report (see section 2.1 Seveso III Directive).

A summary list of the hazard consequences associated with hydrogen are included in **Table 1**. Potential causes and possible mitigating measures is given in **Table 2**. All of these key words are used as "guide" or "prompt words" (with variations) in qualitative risk assessment workshops such as the HAZIDs to trigger open discussions with the workshop participants.

Fire
- Flash Fire
- Jet Fire
- Pool Fire
Explosion
- BLEVE
- Vapour Cloud Explosion
- Flash Fire
Exposure
- Asphyxiation
- Blast Overpressure
- Cryogenic/Cold Burns

Table 1 Summary of hazard consequences

Causes	Hazardous situations	Hazards	Safeguards / Mitigation
Incorrectly planned or incorrectly performed maintenance Incorrect operational procedures (e.g. cooling down, purging and draining, connection/disconnection) Design flaws, wear, tear and fatigue Excessive loads due to dropped objects, impacts from ships and trucks Ships mooring failure or unplanned movement of truck Excessive allowable tension in arms/connections Weather Human error Faults in the alarms system Loss of communication Power failure Third party fires Failure of QC/DC or ERC equipment Overpressure of transfer systems caused by thermal expansion or vaporisation of trapped LH_2 Etc…	Loss of containment (LOC) from hard arms, hoses and/or connections Leaks due to overfilling of tanks and over-pressurisation of ships bunker tanks Leaks due to contamination of bunker lines (e.g. moisture, CO_2) Electrical hazards, other possible ignition sources, activities inside the safety zone, gas dispersion beyond safety zone Accidental release of inert gas	Jet fire, pool fires, confined explosion Vapour dispersion, remote flash fire Brittle fracture of unprotected structural steel when exposed to LH_2 Cryogenic burns from liquid or vapour spills, cold vapour inhalation Asphyxiation (low oxygen atmospheres) Boiling Liquid Expanding Vapour Explosion (BLEVE) Liquid to gas expansion (LH_2) Embrittlement (H_2) Corrosion (H_2) **Possible Effects:** Structural failure and escalation Injuries / fatalities to personnel Damage to equipment and safeguards Secondary fires Escape and evacuation restrictions Etc…	Detailed operational procedures Safety relief valves for all isolatable sections Emergency medical services familiar with cryogenic hazards Cryogenic Spill Protection Stainless steel, aluminium in areas potentially exposed to cryogenic loads Water curtains Inerting and draining of lines Training of involved personnel Maintenance planning Firefighting equipment Communication, emergency and evacuation plans PPE Linked ESD ERS and breakaway coupling Gas and low temperature detection CCTV, dedicated watches Hazardous area protected equipment Fixed/portable fire-fighting Drive away protection on trucks Overfill protection Ventilation arrangements Relief valves, drip trays, bunding Etc…

Table 2 Operational Hazards

3.1.1. Properties of Hydrogen

The physical properties of hydrogen and methane are summarised in **Table 3** for comparison purposes as LNG (comprised mainly of methane) is now widely used in the shipping industry.

Physical Properties of Fuels		
Property	**Substance**	
	Hydrogen	**Methane**
Chemical formula	H2	CH4
Molecular weight	2.016	16.04
Atmospheric boiling point (°C)	-252.9	-161.5
Liquid specific gravity		
(relative to water = 1)		0.422
(at -160°C)		0.546
(at -88.6°C)		0.590
Gas specific gravity (relative to air = 1)	0.0696	0.55
Lower Flammable Limit (% v/v)	4.0	5
Upper Flammable Limit (% v/v)	75.0	15

Table 3 Physical properties of Hydrogen and Methane

3.1.2. Fire and explosion hazards

Different types of fire hazard may arise, depending on whether it is gaseous or liquid that is released. These fire hazards include jet fires, flash fires and pool fires. In certain circumstances, vapour cloud explosions (VCEs) may also occur.

3.1.2.1 Jet fires

A jet fire is a strongly directional flame caused by burning of a continuous release of pressurised flammable gas (in this case natural gas) close to the point of release. Ignition may occur soon after the release begins; or may be delayed, with the flame burning back through the cloud (i.e. as a flash fire, see below) to the source. Jet fires may result from ignited leaks from process equipment (vessels, pipes, gaskets etc.) and pipelines.

A jet fire may be directed horizontally or vertically (or at some angle in between). A jet fire may impinge on structures or other process equipment, giving a potential for escalation of the incident. The intensity of thermal radiation emitted by jet fires can be sufficient to cause harm to exposed persons.

3.1.2.2 Flash fires

Flash fires result from ignition of a cloud of flammable gas or vapour, when the concentration of gas within the cloud is within the flammable limits. In this case, the flammable cloud may be generated by:

- A release of pressurised flammable gas (i.e. H2); or,
- Vaporisation of a pool of volatile flammable liquid (i.e. LH2).

Typically, a flash fire occurs as a result of delayed ignition, once the flammable cloud has had time to grow and reach an ignition source. In the absence of confinement or congestion, burning within the cloud takes place relatively slowly, without significant over-pressure. It is assumed that thermal effects are generally limited to within the flame envelope where there is a very high probability of death.

3.1.2.3 Pool fires

Ignited releases of flammable liquids (including LH2) tend to give rise to pool fires. As with jet fires, ignition of the liquid pool may occur soon after the release begins or may occur as a result of flashback from a remote ignition source, if the liquid is sufficiently volatile to generate a cloud of flammable vapour.

3.1.2.4 Vapour cloud explosions

When a cloud of flammable gas occupies a region, which is confined or congested, and is ignited, a vapour cloud explosion results. The presence of confinement (in the form of walls, floors and / or a roof) or congestion (such as the pipes, vessels and other items associated with process plant) in and around the flammable cloud results in acceleration of the flame upon ignition. This flame acceleration generates blast over-pressure. The strength of the blast depends on a number of factors, including:

- The reactivity of the fuel;
- The degree of confinement or congestion;
- The size of the congested / confined region occupied by the flammable cloud; and,
- The strength of the ignition source.

It should be noted that a variety of objects may act as confinement/congestion, in addition to those normally encountered on process plant. This includes areas of dense vegetation bordering the site.

3.1.3. Risks to persons

The extremely low (cryogenic) temperature of LH2 means that it can cause burns if it comes into contact with exposed skin. Furthermore, inhalation of the cold vapours generated by LH2 can cause damage to the lungs (so-called ‘frosting of the lungs’).

Asphyxiation is also a risk when there are high concentrations of hydrogen. This is because it can displace the ‘breathable air’. Persons need approximately 18% oxygen, and levels below this can be dangerous and result in loss of consciousness and / or fatality.

3.1.4. Solidification of condensables

All other gases other than helium will condense and solidify at the holding temperatures of liquid hydrogen. It is therefore possible that during an LH2 release, the atmosphere could become enriched with solidified oxygen creating an environment that is easier for combustion to occur.

3.1.5. Para-ortho conversion

At ambient conditions hydrogen exists as approximately: 75% ortho and 25% para, whereas the equilibrium liquid hydrogen exists as 0.2% ortho and 99.8% para. The para-fraction increases with decreasing temperature. The transformation of these states, in a liquid hydrogen phase, has an impact on the reliquification capacity and relief valve capacity on board the vessel. The consequences of transition are dependent on the ability to manage flammable gas or the ability of the system to reliquefy. The interim recommendations for the carriage of liquefied hydrogen in bulk has the following recommendation: as per MSC.420(97), Special Requirement No.18 “Only almost pure para-hydrogen (i.e. more than 95%) should be loaded in order to avoid excessive heating by ortho- to para-hydrogen conversion”

4. Alternative Design Arrangements

With no prescriptive rules and regulations in place for hydrogen systems an Alternative Design and Arrangement (AD&A) approach should be followed, as described in IMO MSC.1/Circ. 1455 **[14]**, to demonstrate that an adequate level of safety is achieved in any AD&A. The methodology laid out in the circular considers initially completing a preliminary design review on the system, which as a minimum should include a Hazard Identification (HAZID) Study, and then additional risk and reliability studies will be required as the design matures, including the consequence modelling of credible fire / explosion events.

4.1. Hazard Identification (HAZID)

The HAZID provides a qualitative risk assessment. Carried out as a workshop meeting with a multi-disciplinary team using structured brainstorming techniques and checklists to trigger discussions, it is aimed at quickly identifying, describing and assessing hazardous situations and assigning qualitative risk values to the identified hazards, associated with the installation, integration and operation of the system assessed.

The HAZID study should follow a recognised methodology, with guidance from the following sources:

ISO 31000: 2018, Risk Management –Guidelines **[11]**

IEC 31010: 2019, Risk Management – Risk Assessment Techniques **[12]**

HAZID prompts and 'What if?' scenarios prepared prior to the workshops shall be applied, initiating and encouraging discussions on possible events that may lead to unplanned incidents. These prompts shall be based upon previous experience and indicate the types of hazards that are thought to be applicable.

Possible causes and consequences shall be considered, to facilitate an understanding of the level of risk associated with a particular hazard, a consequence and likelihood shall be assigned and compared to a risk matrix, similar to that shown in **Figure 1**.

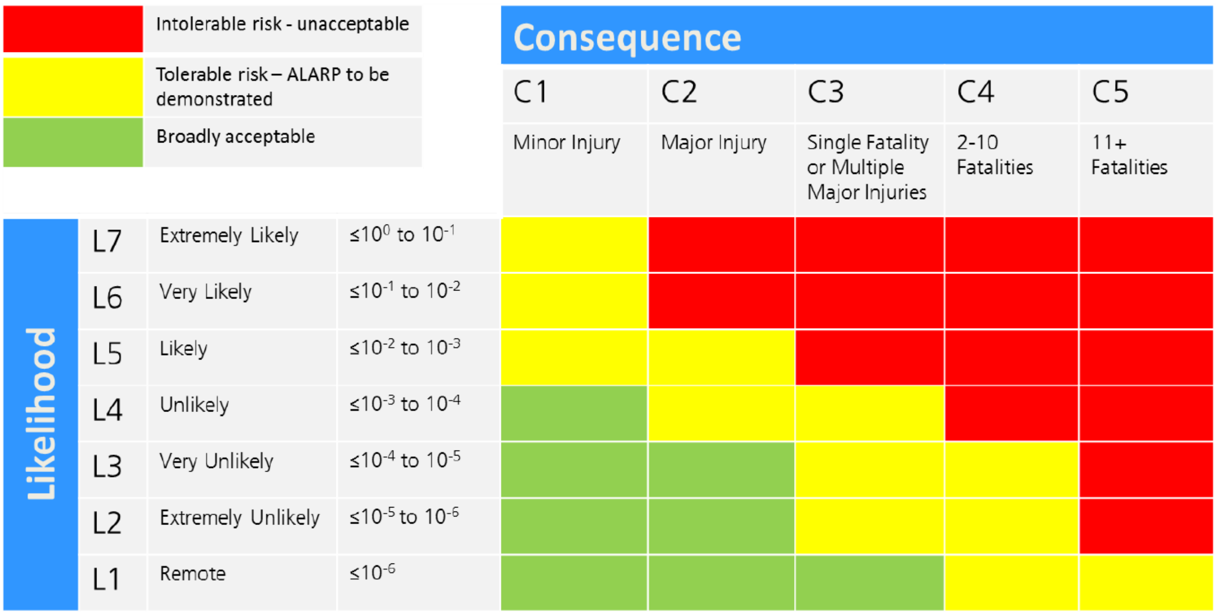

Figure 1 Risk Acceptance Criteria

The risk acceptance criterion reflects 'good practice' in major hazard industries regulated by governments and is recognised by the UK Health and Safety Executive (HSE) as a good basis for use.

The matrices identify three risk zones:

High Risk (Unacceptable) - This level of risk cannot be justified and the hazard should be eliminated, substituted or controls implemented to reduce the risk to tolerable levels.

Medium Risk (Tolerable) – This level of risk can only be tolerated where it has been demonstrated to be As Low As is Reasonably Practicable (ALARP). This can be demonstrated by analysis to assess whether the implementation of risk mitigation measures are proportionate to the reduction in risk they would achieve.

Low Risk (Acceptable) – This level of risk does not need to demonstrate ALARP, however, it is good practice to implement measures to further reduce the risk where possible. The risks should be periodically reviewed to ensure they remain in this region.

To demonstrate ALARP High and Medium risks shall prompt further discussions on whether existing safeguards are sufficient; or additional layers of protection shall be identified. An action list shall be compiled to track items requiring further work.

An important part of the HAZID workshop is the team. The HAZID team should consist of 12 to 15 persons, providing multi-discipline expertise in the fuels, the design of the systems, the ships operations, flag and class.

4.2. Learnings from the ISHY Projects

Due to a number of issues throughout the project, there was limited information available on the hydrogen systems to complete as many risk assessments as originally planned.

A Hazard & Operability (HAZOP) Study was completed on the zepp.X150 Fuel Cell System designed by zepp.solutions on 10 March 2023.

Based on the mitigation measures and safeguards already included in the system design, no significant safety risks were identified that could not be mitigated by further design enhancements. To support this, eight recommendations were made. These were related to:

- Design enhancements that could be made to the ventilation systems through additional control and monitoring systems and the introduction of redundancy in the critical equipment.
- Installation of additional gas detectors at locations were H2 crossover could occur and duplication of instrumentation to avoid spurious alarms / system responses.
- Completion of further assessments on the system (many of which had already been completed on zepp.solution's smaller unit).

Installation of such systems onboard a ship can be subject to additional requirements when compared to land-based applications, especially when they form the main source of power for propulsion and steering systems. It is expected that within the next 12 to 18 months mores specific

Rules and Regulations shall be developed for these systems, which will greatly support the safe implementation of them onboard vessels.

5. Bunkering Operation

The location where bunkering takes place can be considered as a specific location where hazardous substances are handled, and may therefore be subject to consideration for application of Seveso III Directive **[1]**.

The objective of a bunkering operation is that a ship can bunker safely, reliably and with high integrity levels. This means avoiding hazardous situations (e.g. liquid or vapour leaks, ignition of flammable clouds, cryogenic burns) on the ship or at the bunkering facility during all stages of the operation, including: connection and disconnection, the monitor and control phase and any potential emergency scenarios.

For hydrogen the most common bunkering method is Truck-To-Ship (TTS), however as the hydrogen economy grows, more onshore infrastructure projects are likely to follow.

5.1.1. Bunkering systems and components

The starting point to guarantee safe bunkering operations is to ensure that the systems and components used in bunkering operations are designed, manufactured, tested and installed in accordance to recognised standards, national regulations and quality management. It might occur that a recognised standard does not exist; hence in the absence of recognised standards, a qualification programme shall be adopted to ensure safe system and components.

In addition, a quality control programme has to be in place to guarantee quality of the organisation, the design, procurement, components manufacture, storage, transport and construction of the overall system and components.

5.2. Simultaneous Operations (SIMOPs)

Simultaneous Operations (SIMOPs) are considered bunkering plus one or more (other activity) taking place at the same time.

A SIMOPS risk assessment is conducted when, in addition to bunkering operations, the owner/operator would like to carry out cargo operations, deliveries of stores, embarking / disembarking of passengers or bunkering with passengers on board the receiving vessel. The main risk concern is that parallel and additional activities to bunkering at the receiving vessel could either initiate a Loss of Containment (LOC) or contribute to the escalation in the severity of an initiating hazardous event.

The initial SIMOPS risk assessment is normally conducted as an extension of the HAZID workshop to qualitatively assess associated risks while making use of the HAZID multidisciplinary team already gathered for the HAZID workshop. The process is similar to a HAZID:

- Identify the SIMOPS operations that may potentially threaten bunkering operations and the SIMOPS modes of operation.
- Provide a SIMOPS qualitative risk picture

- Identification of risk mitigation measures
- Assess whether those operations should be prohibited or allowed under controlled conditions (hence the risk assessment)

The agreed mitigating measures can be managed in different ways, e.g. incorporated into the operations manual, added in the standard operating procedures, and further quantitative risk analysis activities might follow the initial SIMOPS risk picture.

The examples of regular and planned operation that might be considered as SIMOPs are listed in **Table 4**.

<table>
<tr><th>Regular and Planned Operations</th></tr>
<tr><td>People/passenger/crew movement
Passenger/vehicle embarking/disembarking near bunkering
Vehicle movements delivering passengers/crew/visitors</td></tr>
<tr><td>Cargo loading/unloading
Lifting of cargo from/to dockside to/from ship
Loading/unloading of heat generating or other hazardous cargoes
Operation of hatch covers
Loading/unloading of pumped cargoes and solid cargoes using conveyor belts that may create static electricity
Loading/unloading cargoes that create noise and airborne dust</td></tr>
<tr><td>Loading supplies and removing waste
Service vessels/deliveries (e.g., stores, port officials, oil bunkers, lube oils, crew change, laundry and garbage collection)</td></tr>
<tr><td>Port/terminal activities
Construction and maintenance activities
Operation of local generators (sparking engines)
Hot work, welding, grinding or paint removal (using a blow torch)
Disposal of waste and rubbish by burning
Vehicle movements</td></tr>
<tr><td>Maintenance, inspection and cleaning of vessel areas and equipment
Use of non-intrinsically safe electric or sparking machinery or tools
Testing of stabilisation systems
Testing of high-power radio and radar systems
Testing of ballast water systems
Maintenance and testing of power generation systems (black-out concerns)
Maintenance and testing of control systems (full functionality not available/spurious alarms distract)
Testing of cargo equipment (cranes, conveyors, pumps, and so on)
Control system software upgrades (local or centralised systems)
Hold cleaning
Inspection of hull using divers
Maintenance and testing of non-intrinsically safe electrical equipment
Cabin/common area cleaning</td></tr>
<tr><td>Monitoring of mooring lines, particularly between bunker vessels and gas-fuelled ships
Lifeboat drills
Ballasting operations
Simultaneous bunkering with other fuels</td></tr>
<tr><td></td></tr>
</table>

Table 4 Examples of Regular and Planned Operations

5.3. Other supporting risk studies

The particular studies mentioned in earlier sections might be supported further by additional semi-quantitative risk studies / techniques, such as:

Bow-ties, which assesses how barriers prevent the top events being realised for each hazard initiating event, fault trees, event trees can all provide valuable tools to support the process.

HAZOPs, which identifies both hazards and operability problems and draws upon the P&IDs to assess how deviations from the design can lead to safety hazards;

Layer of Protection Analyses (LOPAs) / SIL Assessments, are an extension of the HAZOP and the risk assessment by defining the reliability of instruments and safety instrumented systems;

Failure mode and effects analysis (FMEA), which identifies the equipment failure modes and their potential adverse effects on the system functionality and objectives;

5.4. Zones for bunkering

The safety zone and monitoring and security area should be established around the bunkering operation in accordance with relevant standards. These zones are in addition to the established practice of setting the hazardous zone that will be required around areas with the potential for the formation of an explosive atmosphere, such that ignition sources can be controlled.

The safety zone shall not be less than the hazardous areas or the minimum distance defined by the regulatory authorities. The hazardous zone is present at all times unless the equipment has been purged with an inert gas. The safety zone and monitoring and security area are temporary, which only exist during the bunkering operation. Once bunkering is completed, the safety and monitoring and security zone' restrictions are lifted. The generally accepted methods for defining the safety zone are:

5.4.1. Deterministic approach

It is common to report distances to smaller concentrations (e.g. 30-50% LFL) to account for gas dispersion uncertainties.

The determination of safety zone study receives input from the accidental scenarios discussed in the HAZID (and other risk assessments) with the following information.

- The physical properties of released fuel
- Weather condition at the bunkering location; wind speed, humidity, air and surface temperatures. The chosen conditions
- Roughness of the surface over which the gas dispersed (i.e. land or water)
- Structures and physical features that could significantly increase or decrease dispersion distances)
- Release rate, release orientation, release height and available inventory

5.4.2. Probabilistic approach

An alternative approach to setting the safety zone is through Quantitative Risk Assessment (QRA) whereby consideration is given within a predefined scenario to a representative set of potential releases and the likelihood with which they occur. This approach is often referred to as the 'probabilistic' or 'risk based' approach.

A key feature of QRA is that it accounts for both the consequence and likelihood of releases and can consider the location of people, the probability of ignition, and the effectiveness of mitigating measures and other emergency actions. As such, it can provide increased understanding of those releases that contribute most to the risk profile. This can be useful in identifying and testing the suitability of mitigating measures, and optimizing zone extents.

5.4.3. Monitoring and security area

The monitoring and security area should be set based upon ship/port operation and should be larger than the safety zone. In setting the zone consideration should be given to activities and installations that could endanger the bunkering operation or exacerbate an emergency situation. For example, consideration of the following is required when setting the security zone:

- Crane and other loading/unloading operations
- Construction and maintenance works
- Utilities and telecommunication activities and infrastructure
- Any other factors considered important by the responsible authority

5.5. Quantitative Risk Assessment (QRA)

There are several situations when a QRA study might be required (law, deviations from standard practice, functional requirements, uncertainty, etc.). This could lead to calculating risk contours for comparison against quantitative acceptance criteria, demonstrate that the safety targets are met, assess safeguards and provide risk reduction measures.

The QRA is a detailed risk assessment study that quantifies both the frequency and the consequence of the accidental events to estimate the risk to people (individual risk and societal risk). The QRA shall be conducted according to standard and internationally accepted quantitative risk assessment techniques.

The study consists of five steps:

- *MAE definition*: the accidental failure case events to be modelled in the QRA are defined, considering bunkering inventories in the segments, pressures, temperatures, leak rates (leak size), gas/liquid phase.
- *Frequency analysis*: for each of the accidental releases, their release frequencies are estimated. The release frequencies are normally based on equipment counts of the bunkering system, operation and can be combined with failure frequency database. Use of historical/common failure data is more suitable than low experience frequency. And then, the final event frequencies are estimated considering probabilities (e.g. ignition, detection, explosion, etc.)

- *Consequence assessment*: the consequence for all the accidental events is assessed to estimate the impact on people or property damage. Conditional inputs such as weather, ignition probability, release direction, surface roughness, etc. should be considered in the impact calculation. These should reflect the operational and location specific conditions (such as weather, persons, ignition sources).

- *Risk assessment*: Once the frequencies and the consequence for each accidental event have been obtained, these are combined to assess the overall risk. For bunkering, individual risk contours and societal risks might be reported. The risk results are then compared against the risk acceptance criteria to check whether they met the requirements or further risk mitigation is needed.

- *Reporting*: the report shall document all the input data, assumptions, the approach followed, the results, conclusions and recommendations. The feasibility and implementation of the assumptions, safety measures and findings in the operational procedures, training and emergency plans should be guaranteed. Ultimately, the risk report can be submitted to the authorities as part of the deliverables to obtain the bunkering operations permit.

- *Sensitivities (optional)*: uncertainties are introduced in the risk assessment mainly through the frequency and probability analyses. Therefore, it is recommended to conduct sensitivities to identify any uncertainties in the results by changing parameters such as failure rates, ignition probability input, etc. This will help getting a more robust quantitative risk results.

References

[1] Seveso III-RL - Seveso-III-Directive (2012/18/EU), July 4, 2012

[2] MARPOL - International Convention for the Prevention of Pollution from Ships - Articles of the Protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, 1973, IMO

[3] SOLAS - International Convention for the Safety of Life at Sea, IMO

[4] IGF - International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels, IMO

[5] IGC - International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, IMO

[6] The International Maritime Dangerous Goods (IMDG) Code, IMO

[7] ISO/TC 197 Hydrogen technologies

[8] ISO 19880 Gaseous hydrogen - Fuelling stations

[9] ISO/TR 15916:2015 Basic considerations for the safety of hydrogen systems

[10] ISO 24132 Ships and marine technology — Design and testing of marine transfer arms for liquefied hydrogen – DRAFT

[11] ISO 31000:2018 Risk management - Guidelines

[12] ISO 31010:2019 Risk management - Risk assessment techniques

[13] IEC 60079-10-1:2020 Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres

[14] IMO Publications and Documents - Circulars - Maritime Safety Committee - MSC.1/Circular.1455 – Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments – (24 June 2013)