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TOWARDS SAFETY BARRIER ANALYSIS OF HYDROGEN POWERED MARITIME VESSELS

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ABSTRACT

This paper focuses on the use of safety barrier analysis, during the design phase of a vessel powered by cryogenic hydrogen, to identify possible weaknesses in the architecture. Barrier analysis can be used to evaluate a series of scenarios that have been identified in the industry as critical. The performance evaluation of such barriers in a specific scenario can lead to either the approval of the design, if a safety threshold is met, or the inclusion of additional barriers to mitigate risk even further. By conducting a structured analysis, it is possible to identify key barriers that need to be included in the system, intended both as physical barriers (sensors, cold box) and as administrative barriers (checklist, operator training). The method chosen for this study is the Barrier and Operational Risk Analysis (BORA) method. This method, developed for the analysis of hydrocarbon releases, is described in the paper and adapted for the analysis of cryogenic hydrogen releases. A case study is presented using the BORA method, developing the qualitative barrier analysis. The qualitative section of the method can be easily adapted to vessels of different class and size adopting the same storage solution. The barrier analysis provides a general framework to analyze the system and check that the safety requirements defined by the ship operator and maritime certification societies are met.

NOMENCLATURE

BBD	Barrier block diagram
$BORA$	Barrier and operational risk analysis
CNG	Compressed natural gas
FTA	Fault Tree Analysis
GHG	Greenhouse gas
LNG	Liquified natural gas
O&G	Oil and Gas
RID	Risk influencing diagram
RIF	Risk influencing factors
TCS	Tank connection space

INTRODUCTION

In recent years, a strong environmental consciousness has developed in industry, government and society. New plans have been put into action to reduce emissions along shipping routes and in smog choked coastal cities. The UN Sustainability Development Goal number 14 calls for reduced emissions in the oceans, and new commitments by the International Maritime Organization aim to reduce of 50% Greenhouse Gas emissions by 2050 with respect to 2008 levels [1]. Emissions control can also be used to preserve natural sites. In Norway, the aspiration of the government is to have an emission-free zone in its world heritage Fjords no later than 2026 [2]. This means that finding a carbon-free energy carrier that can deliver similar

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performances to fossil fuels is now a priority for the maritime industry.

The use of hydrogen could provide a carbon-free alternative to ship operators without sacrificing range and flexibility. Fuel cell systems can provide a long range zero-emission solution for vessels that cannot be operated on just batteries due to range limitations. The use of hydrogen as an energy carrier not only would diminish harmful emissions, but would also reduce the risk of spillage of harmful hydrocarbons in the sea in case of vessel damage. Hydrogen reserves can be replenished using off-peak power produced by renewable energy, but there are a series of challenges to be overcome regarding safety. Designing hydrogen systems is non-trivial when factoring in the low density, wide flammability range and low ignition energy. The physical and chemical behaviour of gaseous hydrogen and cryogenic hydrogen has always proven to be a critical factor for manufacturers willing to develop transport systems using this energy carrier.

Defining a framework that engineers can use during the design of a hybrid hydrogen vessel to systematically identify critical safety issues is of the utmost importance. For this task, this paper considers on an established methodology from the Oil & Gas (O&G) industry, the Barrier and Operational Risk Analysis (BORA-Release method) method. This method is applied for identification, investigation and performance evaluation of safety barriers. In this paper, the method is used to identify and investigate barriers related to the storage of cryogenic hydrogen on-board a vessel and how these may fail. The method's structure includes a qualitative part, used to identify weaknesses in the vessel's architecture, and a quantitative part, used to quantify the performance of the barriers by calculating the new frequency of the initiating event and the probability of barriers failure using collected data. In presented work the focus is on the qualitative part that can be used as the basis for further developments including the formulation of Bayesian networks, and the organization of workshops for the classification of critical scenarios and the evaluation of scores assigned to dangerous system or organizational failures.

Following the definition of the BORA method, a case study is developed considering the release of cryogenic hydrogen below deck. The case study investigates which safety barriers could be put in place for this specific scenario and their effectiveness. The safety barriers are defined according to the numerous studies developed on the topic [3–5]. The main goal is to contribute to the development of hydrogen systems in the maritime industry and provide a valid tool for ship designers and engineers in the design phase of fuel cell hybrid vessels.

HYDROGEN MARITIME SAFETY

Technical business services organisations and maritime classification societies are formulating a series of standards and regulation for hydrogen powered vessels. These standards are created from the ground up as there is no real precedent for applications, in the megawatt range, of hydrogen in the maritime industry. It is also not possible to use the same standards used for LNG or CNG due to the different physical and chemical differences with hydrogen. The standards to ensure the safe transportation of passengers and goods are being developed in cooperation with the companies that aim to sail hydrogen vessels as soon as 2023. An example would be the project for the Norled ferry [6] in Norway and the Flagship Project [7] in France.

Among the published studies on concept risk assessments related to fuel cell vessels, it is possible to find the studies of Aarskog et al. [8] and Klebanoff et al. [9]. These studies offer an insight into the applications of fuel cells for maritime transport, focusing on fast passenger vessels equipped with power-plants in the range of 500 kW and high pressure gas hydrogen storage above deck. Placing the hydrogen pressure vessels above deck is the safest solution, using natural ventilation to disperse the gas, as demonstrated by Aarskog, complying with the general regulations from the International Code of Safety for Ships Using Gases or Other Low Flash-point Fuels [10].

Comprehensive studies on larger vessels, like double ended ferries or coastal cargo ships in the 5 to 10 MW power range, still need to be fully developed. In these cases, a below-deck storage solution might be dictated by weight distribution and footprint usage constrains. Below deck storage introduces a series of specific scenarios, with more complex dynamics than the on-deck storage solutions, that it is possible to analyze systematically with the method presented in this paper.

When considering below deck storage, a series of studies has been reviewed to account for the differences between cryogenic hydrogen and LNG. For scenarios of vented and dispersed hydrogen due to tank overpressure, the studies of S.B. Dorofeev [11] and Gavelli et al. [12] enable the definition of how the dispersion of the gas should be carried out to avoid creating dangerous conditions. The dispersion technique and conditions heavily influences the design of the vessel as dedicated ventilation passages, like a mast riser, needs to be integrated in the vessel's structure. The release of cryogenic hydrogen, generated from tank rupture or valve leakage, has been analyzed by O. Hansen [13] in his studies focusing on hydrogen dense gas behaviour. In Hansen's study, multiple computational fluid dynamics models show the influence of wind and humidity when hydrogen is released and vented through the mast riser of a large vessel. The paper also confirms how safety barriers put into place by the industry for LNG are not sufficient for hydrogen-based solutions. The studies from Giannissi [14] and Hall et al. [15] also provide a valuable insight in the risk assessment of vessels operating with liquid hydrogen as they model dispersion conditions and ignition in various scenarios, in closed and semi enclosed spaces.

SAFETY BARRIER DEFINITION

Haddon [3] defines safety barriers as the measures taken to separate, in space or time, a possible victim from the sudden release of energy originating from a uncontrolled source. These measures can be considered as tangible asset of the system or can include operational and administrative measures. For Johnson [4], a barrier consists of the physical methods to direct energy in wanted channels and control unwanted releases, while Larsson [5] states that the definition of barrier can be expanded to include not only physical measures but also administrative measures, such as procedures and work permit systems. According to Sklet [16], including both physical and/or non-physical means planned to prevent, control or mitigate undesired events or accidents, gives us an improved likelihood of identifying the most weaknesses in a system. Following Sklet's guidelines and Larsson's definition, in this paper, the process of barrier identification is carried out considering both physical and administrative measure. This allows a more comprehensive analysis of the system.

A classification has to be made between proactive barriers and reactive barriers [17]. Reactive barriers are included in the system to respond to already occurred critical events. Proactive barriers act to prevent the dangerous circumstance by triggering appropriate countermeasures. Proactive and reactive barriers are both implemented in complex systems, as the prevention of the critical event is not always possible, and reactive barriers need to step in and control the consequences of previous barriers failure. A key factor to consider in safety barrier analysis is not just the identification of the barriers but also the definition of their interaction. The idea is that barriers are arranged in a multi-layer configuration to ensure avoidance, prevention, control and protection against unexpected dangerous scenarios [18]. Even if one, or more barriers, fail due to latent conditions or active failure measures, the energy release encounters immediately another barrier to control the situation.

Many sectors dealing with complex systems, from a technical and organizational point of view, have examined critical scenarios and accidents with methods based on safety barrier analysis, creating numerous effective applications of this theory [19–21].

BORA METHOD APPLICATIONS FOR HYDROGEN SAFETY

The choice of the method to conduct the barrier analysis for hydrogen release scenarios was carried out in light of the inherent dangerous nature of the fuel and the system's complexity. The Barrier and Operational Risk Analysis (BORA) Release method [22], proves to be fitting our requirements, as it provides to be a solid framework divided in 8 steps to calculate the risk of specific energy release scenarios and identify possible "weak links" in the organization from a safety point of view.

1. **Method fundamentals**: Definition of the boundary condition for the study with respect to a specific scenario. In this case, the section will include physical and chemical properties of the hydrogen, a literature review on the system's components, information on the vessel taken into consideration, etc.
2. **Barrier Block Diagram (BBD)**: This step consists of three actions: (1) Identification of the initiating event for the considered scenario, (2) definition of the barriers implemented to deal with the given initiating event, (3) definition of the outcome in case of barrier success or failure in containing the release of energy. Once identified all the elements it is possible to plot the BBD following the guidelines from the original BORA method.
3. **Risk Influencing Diagram (RID)**: In the risk influencing diagrams are collected the possible factors that lead to the initiating event. These factors can be technical or operational.
4. **Barrier performance evaluation**: In this steps, a fault tree analysis (FTA) is created for each one of the barriers identified in Step 2.
5. **Frequency of initiating event**: Assigning a industry average probability/frequency to the initiating event for the final calculation of the scenario specific risk.
6. **Scoring and Weighting of risk influencing factors (RIFs)**: for the final calculation of the scenario specific risk.
7. **Adjustment of industry average probabilities / frequencies**: By creating a table with the industry average probabilities/frequencies, scores and weights of RIF, it is possible to revise the probabilities/frequencies before starting with the calculation
8. **Calculation of the risk** in order to determine the scenario specific risk.

The steps indicated above can be developed for each single scenario that is deemed critical or a source of possible risk. In this paper, the aim is to focus on the qualitative section of the method (step 1 to 4), laying down the basis for the adaptation of the BORA method to hydrogen. Further steps (from 5 to 8) are developed at a later stage as they are tied to the specific vessel design and require the formulation of extensive Bayesian network and expert validation through workshops.

To limit the study in this paper, the case presented analyzes one scenario in relation to the on-board storage of cryogenic hydrogen and its release below deck. The release event conditions and safety barriers choice derives from both literature review on the state-of-the-art of hydrogen behaviour, and from experts interviews. The experts opinions was provided by maritime certification experts with over 20 years of experience and have been collected during the Florø 2019 Conference on Maritime Hydrogen & Marine Energy and at the

Annual H2 Team Workshop of NTNU.

The barrier analysis is developed, and the performances are evaluated according to factors such as:

1 - Functionality or effectiveness
2 - Reliability and availability
3 - Response time
4 - Robustness

FTA is included in the paper qualitatively to provide information about how the barriers may fail and what events or components are most critical in terms of causing barrier failure. The last considered step relevant to barrier analysis is the identification of the most important risk factors and the creation of Risk Influence Diagrams. These help to identify technical challenges in case the initiating event is created by a physical component or bad practices in the industry if the event is triggered by human/procedure error.

The following steps, requiring industry data regarding frequency of events and risk calculation, are left out of the paper's scope and can be implemented at a later time in a more comprehensive approach calculating the effective risk of multiple scenarios.

STUDY CASE: BARRIER ANALYSIS FOR ABOVE DECK STORAGE RELEASE SCENARIO

System description

The case study focuses on the scenario considering the release cryogenic hydrogen from a tank placed below deck, in an enclosed space. The use of hydrogen in cryogenic form is justified on vessels equipped with multi-megawatt power-plants where the higher energy density, compared to the compressed form, allows for more operational range.

Cryogenic tanks can be placed below deck when the system is well integrated in the vessel design, combining technical aspects with a safety barrier analysis.

A series of components and structures need to be installed to allow for the safe use of hydrogen in an enclosed space such as a below deck watertight compartment. First, the design needs to include a tank connection space (TCS), which encloses the valving coming from a LH2 tank in a ventilated box. The TCS ventilation is independent from the ventilation of the Fuel Room containing the tanks. The TCS allows for the controlled venting of hydrogen in a controlled space able to withstand cryogenic temperatures. A mast riser, connecting the TCS to the outside environment needs to be installed, allowing for the safe dispersion of hydrogen in atmosphere.

The cryogenic hydrogen experiences boil-off over time as heat exchange with the outside environment happens. The hydrogen turned into gas can be fed to the fuel cell when its pressure is brought to a value compatible with the fuel cell inlet. The excess gas needs to be vented through the mast and dispersed in atmosphere to avoid ignition. The cryogenic hydrogen is turned into gas at a controlled rate and supplied the fuel cell to generate electricity. It is possible to observe the schematics of the system in Figure 1.

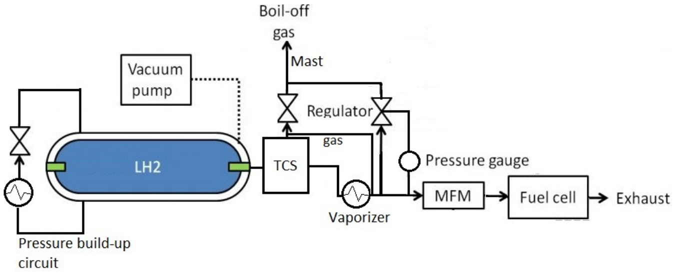

FIGURE 1. System block diagram

The qualitative barrier analysis carried out in this paper is independent on the amount of hydrogen stored on-board. This is due to the fact that hydrogen expands to about 850 times from liquid to gas phase and flammability or explosion limits are reached rapidly even if the quantity leaked is minimal. The interaction between the leaked mass of hydrogen that could reach ignition or explosion limits, and the mass still contained in the tank is not analyzed in this paper.

The case study focuses on the leak of one of the tank valves inside the TCS. While the TCS is a certified component from maritime classification societies, cases where hydrogen is able to escape are a low probability high consequences event that needs to be considered. The escape of hydrogen from the TCS can happen due to improperly sealed connections, or a more catastrophic rupture due to the explosion of the hydrogen inside the TCS.

Qualitative safety barrier analysis

The qualitative safety barrier analysis described in steps one to four of the BORA release method is developed in this section. The goal is to discuss the key elements of the method, the barriers, and their implementation. The focus is on how barriers are determined, how they are included in the barrier block diagram and, finally, how it is possible to investigate their effectiveness. The qualitative analysis from the BORA method provides a generalized analysis for vessels belonging to different sizes, as long as they are equipped with a cryogenic storage method similar to the one described in this paper.

In the considered case, the storage of the cryogenic hydrogen is placed below deck. This case is relevant as many shipyard are considering various locations for the hydrogen tanks to

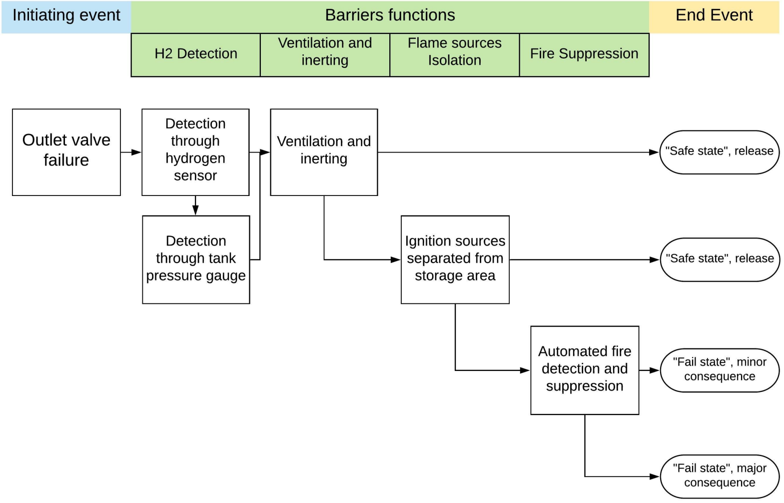

FIGURE 2. Barrier block diagram; scenario "Valve failure due to tank overpressure"

minimize the footprint dedicated to cryogenic storage. The storage of the cryogenic hydrogen is complex and includes multiple valves, piping, heat exchangers and pumps. There is a high number of scenarios that can be analyzed in relation to the system, as the point of possible failure are many. The initiating event considered for this case study is the failure of a valve connected on one side to the TCS and on the other to the vaporizer. This scenario is a high consequences scenario, interesting as in a one-tank configuration all the cryogenic fuel supply passes through the valves contained into the TCS. If hydrogen manages to escape the TCS there is a high likelihood that the limits for an explosive atmosphere are reached in a very short time-span.

With the basic risk model formulated, it is possible to identify the main barriers involved in the considered scenario and build the first BBD. In the BBD the initial event is represented on the left, the barrier functions are represented in the center of the diagram, and in the last column is represented the end event. An horizontal arrow line leading directly to the end event means that the barrier put in place was effective in stopping the threat, leading to an end event, while an arrow line leading to a second barrier function block means that the barrier has failed.

The diagram for the considered scenario can be visualized in Figure 2. The barriers identified as relevant for this scenario fall into the categories of detection, ventilation, isolation and suppression. Two of the indicated barriers are proactive (H2 detection and Flame source Isolation) while the other two are reactive (Fire suppression, ventilation).These four barriers are common to other systems storing cryogenic fuels such as LNG. The difference between the LNG system and the cryogenic hydrogen system lies in how the barriers are implemented. The response time for the hydrogen leak needs to be faster and therefore a sensor able to quickly detect harmful concentration is required. Furthermore the flame source isolation barrier needs to deal with a much wider flammable/explosive concentration range.

Once the barriers have been identified and their order established through the BBD, their performances can be qualitatively investigated. This task can be carried out following the BORA-Release methodology using FTA. The FTA can help analyze the probability that a barrier failure event will occur, identifying a series of factors that have to be taken into consideration when implementing the barrier, such as active or passive redundancy. Figure 3 represents the performances evaluation for the H2 detection barrier, Figure 4 represents the performances of the flame source isolation barrier, Figure 5 is relative to the fire suppression barrier, Figure 6 is relative to the ventilation and inerting barrier. It is possible to observe from the FTA that the barriers can combine both technical and non-technical factors, leading to the barrier failure. This is why a functional approach, as described in the safety barrier definition section, is preferred in this case.

The performances of the hydrogen sensors is dependent on having a constant voltage supplied to the sensor, a good calibration to ensure accuracy and limited noise on the line transmitting the signal. All these factors have to be taken into consideration when implementing this barrier. Hydrogen sensors can today be realized with materials ranging from optical fibers [23] to nano-composite [24], providing a wide range of accuracy, but also different reliability and effectiveness. The detection of hydrogen escaped from the TCS inside the ship's compartment is a critical safety barrier as it has

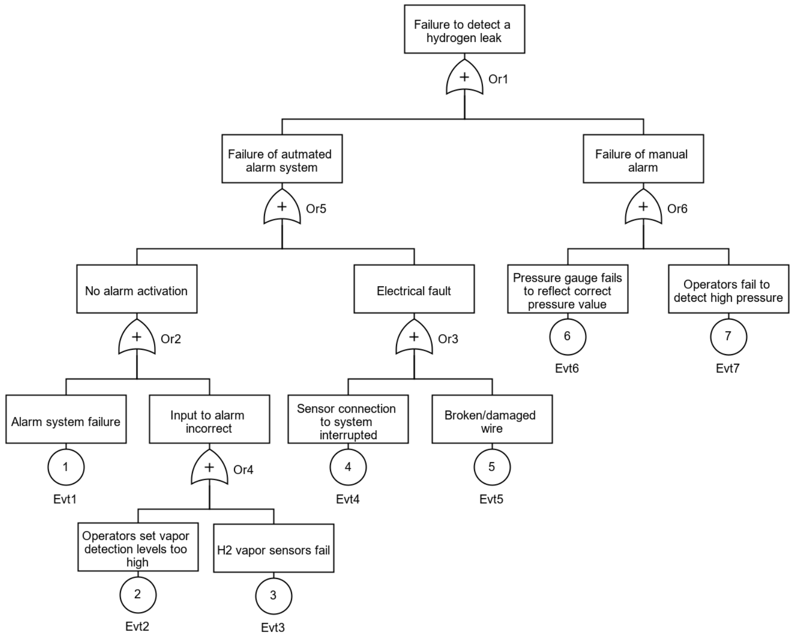

FIGURE 3. Fault tree diagram for H2 Sensor

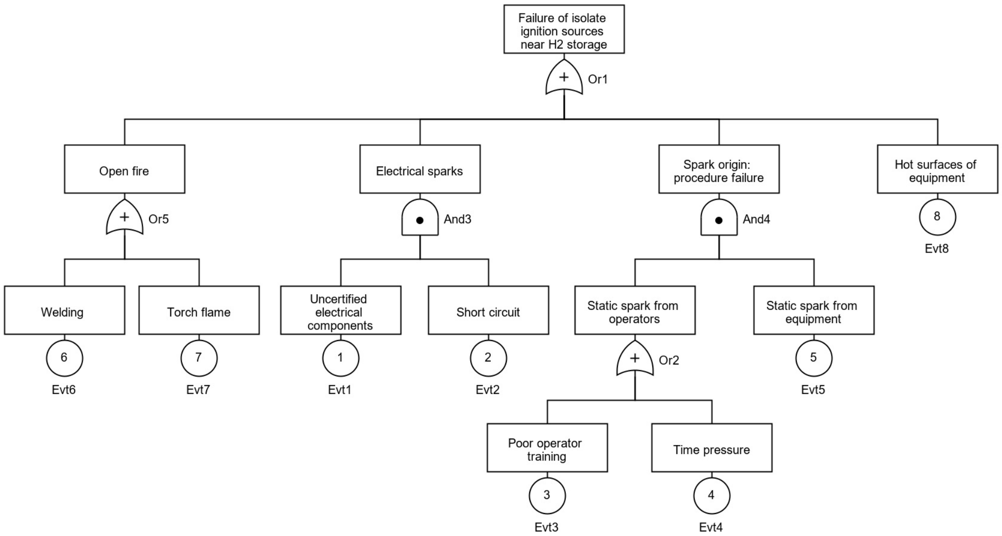

FIGURE 4. Fault tree diagram for flame source isolation

devastating effects if the explosive concentration in air is reached. With optical fibers sensors, depending on both concentration and temperature, detection of concentrations between 1% and 17% with response times shorter than 5 s have been demonstrated [25]. Fast and accurate detection of hydrogen concentrations inferior to the explosive limit is vital to activate the ventilation system and vent the hydrogen to the outside. The release of hydrogen in an enclosed compartment can be also fatal to the crew if undetected, as it may cause asphyxiation. High concentrations of H2 reducing the oxygen level below 19.5% poses a physiological threat to operators that need to evacuate the area.

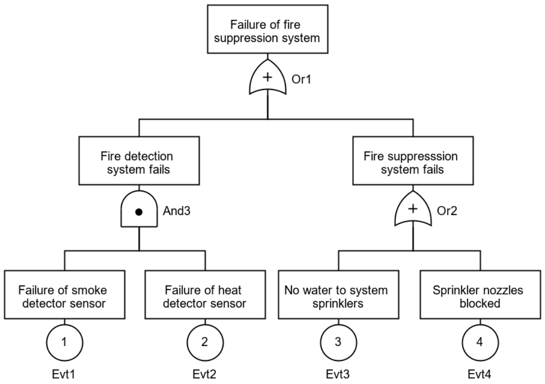

FIGURE 5. Fault tree diagram for fire suppression system

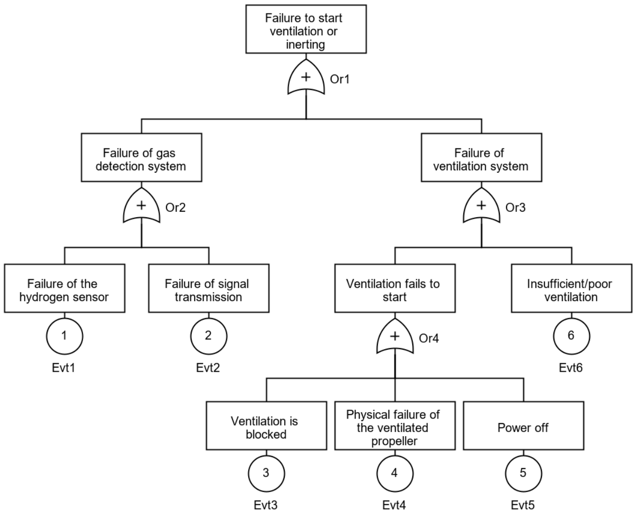

FIGURE 6. Fault tree diagram for ventilation barrier

The second barrier involves ventilation of the compartment in addition to the dedicated ventilation of the TCS. This barrier needs to be implemented taking into consideration the volume of air that needs to be moved considering the effect of buoyancy of the leaked hydrogen in the compartment. The idea is to achieve ventilation producing the 30 room air exchanges required by the U.S. Coast Guard Regulations as safety reference, avoiding strong turbulent flow. References on the interaction of hydrogen releases and ventilation can be found in the work of Cashdollar et al. [26].

The third barrier consists in the isolation of ignition sources (thermal and electrical). This barrier is implemented by avoiding the presence, where the cryogenic storage is located, of equipment that can generate heat or open flames in the compartment or procedures that can generate ignition sources such as sparks. The first solution is defining in the design a safe perimeter or area in which possible electrical sources that could cause sparks or mechanical sources that could cause heat are excluded. This may also include design changes to the routes of pipes carrying steam, hot water or electric cables. Static electricity created by moving objects, water mist, improper storage of polypropylene ropes or operators action could lead also to ignition. Operators should also exercise caution as static discharges from human beings are in the range of 10mJ while the minimum ignition energy for hydrogen is 0.02mJ [9].

The fire suppression barrier is the last resort if the hydrogen is ignited. Hydrogen burns with a colorless flame detectable only from distance with a thermal camera. Hydrogen mixtures ignited at 4% produce very little heat, and flame propagation is almost exclusively upward [9], while at 8% there is a self sustaining fire with propagation in all three directions. Special consideration has to be put into the interaction with the ventilation system and the fire, as has been done in the work of Peatross et al. [27] for more conventional fuels.

Another problem is the choice of the fire extinguishing agent as spraying simple water onto the fire could cause unwanted reactions with the non-ignited spray or splashing in case of the formation of a pool. A method for extinguishing hydrogen fires comprises introducing to the hydrogen fire a fire extinguishing concentration of heptafluoropropane and maintaining the concentration until the fire is extinguished. The method includes heptafluoropropane at a range of 13-30 % volume/volume in the air. The fire extinguishing methods also include the use of heptafluoropropane in blend with other fire extinguishing compounds [28].

Guidelines on how to implement an efficient fire system can be found more in detail can be found in the studies of Bubbico et al. [29].

The risk influencing diagrams are used to model and enhance the frequency/probability estimations of the top events in the fault trees but can also be used to adjust the initiating event (IE) frequency. In this case the RID is used in a qualitative way and laid out for further quantification of the FTA when the quantitative section is developed. This allows for the assignment in further studies of a score from A to F of the individual factors, influencing the final risk evaluation.

For our initiating scenario are listed:

1 - **Technical conditions:** H2 Boil-off
2 - **Material properties:** Seals corrosion or deterioration
3 - **Equipment design:** Insulation defects
4 - **Process complexity:** Excessive storage time
5 - **Maintainability:** System maintanence

The listed factors are represented in Figure 7 in the RID for our specific scenario. It is possible to affirm, even before the assignment of the scores to each factor in the quantitative analysis, that the factor that most heavily influences the probability of the initiating event is H2 Boil-off. This condition is unavoidable with cryogenically stored fuels and is experienced even with the most efficient types of insulation. The Boil-Off problem is a well known challenge in maritime industry and has been extensively explored with LNG [30, 31] even if only part of the knowledge can be transferred due to different physical properties. Other factors have generally an average influence on the initiating event. Excessive storage time, for example, is dictated by time pressure on the operators that can lead to bunker more fuel than needed to save up time during day operations and avoid a second refueling.

With the identification of the risk influencing factors the components of the barrier block diagram presented in Figure 3 have been defined. This, combined with industry realistic scoring/weighting of the factors based on studied release scenarios and an expert assessment on the probability/frequency of the initiating event, should form the core of a the barrier analysis in BORA-Method application for hydrogen releases.

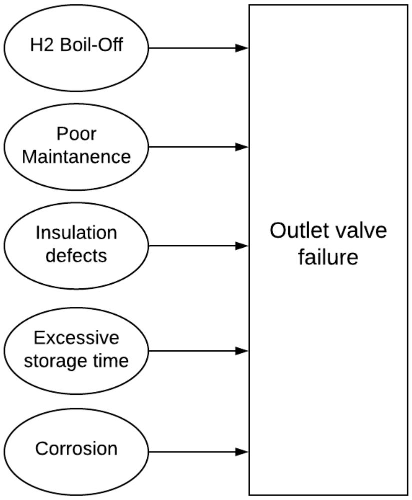

FIGURE 7. Risk influence diagram; scenario "Valve failure due to tank overpressure"

RESULTS AND DISCUSSION

The study case shows that the qualitative section of the BORA-Release method for safety barrier analysis can be used as a valid tool, not only for the release of hydrocarbons, but also for the release of cryogenic hydrogen below deck on a maritime vessel.

This method provides a validated framework to identify and evaluate the safety barriers necessary for the considered scenario. The results of the quantitative safety barrier analysis can aid the design of a vessel powered by cryogenic hydrogen, highlighting measures necessary to reduce the risk of fatal accidents in case of a leak. These measures are identified through fault tree analysis and enclose both technical and administrative aspects. Sensors and physical barriers play a role as important as safety checklists and operators training.

For this specific scenario, the barriers are listed from left to right in the BBD, using the criteria that the more the barrier is placed on the left the less critical are the consequences of its failure. The first barrier, consisting of hydrogen detection, plays a key role in ensuring the safety of the vessel and crew. The second barrier defines the need for a dedicated ventilation system capable of evacuating the flammable gas if detected and avoid reaching explosive concentrations in the storage compartment. The flame source isolation barrier stresses how design choice should meet with the safety concerns for the routing of pipes carrying hot fluid or air and electrical equipment. The fire suppression system is the last barrier and a key system in the containment of the damage if the worst case scenario is considered, ensuring safe return to port if a fire erupts.

From the RID are observed the main factors influencing the frequency of the initiating event, with this being heavily influenced by the physical nature of the fuel. According to many articles like the studies of Zhang et.al [32] H2 Boil-off is definitively the most influencing factor as the pressure build up creates stress on components like valves. Cryogenic storage not only produces stress due possible overpressure but also weakening of the seals due to extreme temperature [33] and therefore creating a maintanence problem. This should be a focus point for designers of the system.

Overall it is possible to say that the qualitative barrier analysis through the BORA-Release method presents itself as a promising approach for the further study of scenarios related to vessels powered by hydrogen or including a hydrogen storage. The quantitative study can be developed following the considerations made in this paper, assigning numerical scores in relation to the probability of certain events and calculating the improvements that the identified barriers bring.

CONCLUSION

The adapted qualitative barrier analysis framework is an effective way to visualize possible technical or procedural weaknesses in the design of a vessel powered by cryogenically stored hydrogen. Once identified, through consolidated tools like barrier block diagrams and fault tree analysis, it is possible to correct them and obtain a robust design. The case study presented is relative to a key topic in the maritime industry: below-deck storage of cryogenic hydrogen.

A simplified analysis related to hydrogen detection, ventilation, flame source isolation and fire suppression system has been carried out. The qualitative analysis of the method provides a base case study, which it possible to further develop with a quantitative analysis using industry data and assigning numerical scores to barrier performance in workshops with system experts.

In general, the development of protocols and method to evaluate the safety of hydrogen solutions in the maritime industry can help make this zero-emission energy carrier more widespread and ensure that passengers and crew members can travel safely both in domestic water and on oceanic routes.

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