BACHELOR THESIS – ME141502

RISK ASSESSMENT OF FUEL SYSTEM ON DUAL FUEL ENGINE OF FERRY SHIP

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MARINE ENGINEERING DEPARTMENT
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SURABAYA

TUGAS AKHIR – ME141502

PENILAIAN RESIKO PADA SISTEM BAHAN BAKAR MESIN DUAL FUEL DI KAPAL FERI

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RISK ASSESSMENT OF FUEL SYSTEM ON DUAL FUEL ENGINE OF FERRY SHIP

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ABSTRACT

The development of the diesel engine in the human life has a positive impact for transportation and industries. Behind the development of diesel engines which quite rapidly, the diesel engines also have a negative effect, air pollution. Therefore actions to reduce the air pollution are needed. One of the actions is by using the alternative energy, natural gas. The use of natural gas as a fuel in the vessel can be done for new ships or ships that already exist. However, the use of natural gas is certainly provide a different construction with oil-fueled ships in their system, which is certainly a risk that can be generated from it. The risk can be analyzed in two perspectives, frequency and severity. There are three main step framework of risk assessment which must to fulfill, there are Risk Identification, Risk Analysis and Risk Evaluation. Risk identification which using HAZOP (Hazard and Operability) method, do by understanding function of all system which will be analyze. Risk analysis is step to determine level of frequency and consequence which will be used as an input for the risk evaluation. The risk evaluation is step for determining if the risk is acceptable or tolerable. If there are 'not acceptable' risk than action should be taken to reduce the risk level or mitigation by using LOPA (Layers of Protection Analysis) method. From 41 failure mode scenarios there are 18 failure mode which has moderate risk level and 1 failure mode on high risk level, rest of failure mode scenario has low risk level. Due to several risk with high consequence category, then the operational of dual fuel must always monitored, to support the monitoring activity a good and reliable items are needed. There for the activity of inspection and maintenance for those items are need to be done periodically.

Keyword: Dual Fuel, Ferry Ship, Fuel System, HAZOP, LNG, LOPA, Risk Assessment.

PENILAIAN RESIKO PADA SISTEM BAHAN BAKAR MESIN *DUAL FUEL* DI KAPAL FERI

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ABSTRAK

Perkembangan mesin diesel selama ini memiliki dampak yang positif bagi kehidupan manusia baik digunakan disarana trasnportasi maupun indusrti. Namun tidak hanya dampak postif saja, terdapat dampak negatif yeng diberikan oleh penggunaan mesin diesel, seperti pencemaran udara. Salah satu cara untuk menanggulanginya adalah dengan menggunakan energi alternatif, seperti gas alam (*natural gas*). Penggunaan gas alam sebagai bahan bakar dapat diterapkan pada kapal baru maupun kapal yang sudah beroperasi. Untuk kapal yang sudah beroperasi maka perlu dilakukan perubahan atau modifikasi pada sistem bahan bakarnya. Perbedaan sistem bahan bakar natural gas dengan sistem bahan bakar pada mesin diesel konvensional tentunya memberikan resiko tertentu yang dapat merugikan secara material ataupun keselamatan. Resiko dapat dianalisa dengan melihat dua faktor yaitu frekuensi dan kosekuensi, dimana tingkat resiko akan terlihat dari hasil perkalian antara frekuensi dan konsekuensi. Terdapat tiga langkah utama dalam penilaian suatu resiko yaitu pengidentifikasian resiko, analisa resiko dan evaluasi. Identifikasi resiko yang menggunakan metode HAZOP (*Hazard and Operability*) dilakukan dengan memahami fungsi dari sistem yang akan dianalisa, hasilnya berupa skenario mode kegagalan pada sistem tersebut. Tahap berikutnya adalah analisa resiko dimana pada tahap ini akan menentukan tingkat frekuensi dan konsekuensinya. Evaluasi resiko adalah tahap untuk menetukan tingkat dari resiko tersebut apakah resiko tersebut berada dalam katagori *acceptable* atau *not acceptable*. Jika ada suatu resiko yang menunjukan *not acceptable* maka perlu dilakukan tindakan pencegahan atau mitigasi dengan meggunakan metode LOPA (*Layers of Protection Analysis*). Dari 41 mode kegagalan 18 diantaranya berada pada tingkat resiko *moderate* dan 1 pada tingkat resiko *high*, sementara sisanya berada pada tingkat resiko *low*. Mengacu pada beberapa resiko yang memiliki tingkat konsekuensi yang tinggi, maka operaisonal pada sistem bahan bakar dual fuel haruslah selalu terawasi, untuk menunjang hal tersebut diperlukan alat-alat yang baik dan handal. Oleh karena itu adanya aktivitas inspeksi and perawatan secara berkala sangatlah direkomendasikan.

Kata kunci: Dual Fuel, HAZOP, Kapal Feri, LNG, LOPA, Peniliaian Resiko, Sistem Bahan Bakar.

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I realize that it is still imperfect but I hope it can be useful for us. Critics and suggestion are needed here to make this thesis better, thank you.

Surabaya, July 2016

Kennychi Harits Syahputra

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CHAPTER I
INTRODUCTION

1.1. Background

The development of the diesel engine in the human life has a positive impact for transportation and industries. Behind the development of diesel engines which quite rapidly, the diesel engines also have a negative effect, air pollution. Air pollution comes from the remnants of diesel engine combustion pollutants which containing elements such as Nitrogen Oxides (NOx), sulfur oxides (SOx), Carbon Monoxide (CO) and hydrocarbons (HC).

Using fuel oil as energy supply on the ship's engine has increasingly high which led to increasing numbers of air pollution. Therefore actions to reduce the air pollution are needed. One of the actions that have been carried out is the imposition of ECAs which is the rule in certain areas that limit the contents of air pollutants, such as those already mentioned. Moreover, the use of alternative energy, natural gas, is also one way to reduce air pollution in the sea. Natural gas which still abundant in this country is expected to be utilized properly as an alternative energy.

The use of natural gas as fuel on the ship have also increased over time. The price of natural gas relative to that of diesel or gasoline can vary widely from time to time and from one location to another. Generally, on an energy basis, natural gas and liquefied petroleum gas (LPG) sell significantly cheaper than diesel fuel and gasoline. In this case the use of natural gas as a fuel will provide economic benefits for the ship company because it can be save the cost for fuel consumption.

The use of natural gas as a fuel in the vessel can be done for new ships or ships that already exist. However, the use of natural gas is certainly provide a different construction with oil-fueled ships in their system, which is certainly a risk that can be generated from it. Every dangers and risks that posed can cause damage on their equipment, economic losses and may harm to the people around it. From the existing problems, there are should be a study for the risks that can be posed, it aims to reduce or eliminate them.

The risk can be analyzed in two perspectives, likelihood and severity, where the amount of the risk is determined by multiplying the value of likelihood and severity. In this thesis will discuss about all the risks and impacts that may be caused on the ship that use natural gas as a fuel.

1.2. Problem Formulation and Scope

The use of natural gas as the main fuel in vessels has begun to used. This is have several positive effect to the environmental if compared to fuel oil, which contained elements of exhaust gases such as Nitrogen Oxides (NOx), Sulfur Oxides (SOx), hydrocarbons (HC), Carbon Monoxide (CO) more higher then natural gas, it is no wonder if many ships start switch to using natural gas as its primary fuel. However, the use of natural gas caused ship to pick different design of the fuel system. Obviously this distinction has a different risk and impact on their system. Therefore, risk assessment on fuel system for the ships which using natural gas as fuel are required to avoid system failures that can harm to people around it.

Based on the description above, presented several problems:

1. What are the risks and failures that can be generated on the fuel system that uses natural gas as fuel?
2. How is the risk level of danger posed from each of the existing failure?
3. How to minimize failure and risk on fuel system?

Scope of Problems:

1. The ship that will be reviewed is the ferry ship that use natural gas as fuel (dual-fuel).
2. Data that are not listed in detail, such as P&ID, will be assumed to follow project guide from the machine manufacture and class regulation which used by ship.
3. Human factor on every failure modes will be ignored.

1.3. Objective

The objectives of this Thesis are:

1. Knowing the risks and failures that can be generated on a fuel system that uses natural gas as fuel.
2. Knowing the risk level of danger that can be generated from existing failure.
3. To obtain a way to minimize the failure and risk.

1.4. Benefit

The final results of this Thesis is the form of safety recommendations for the ferries that use natural gas as fuel.

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CHAPTER II
LITERATURE REVIEW

2.1. Natural Gas

Natural gas is usually the volatile portion of crude petroleum. It normally occupies under high pressure the porous rocks of oil reservoirs above the liquid fuel zone. The gas is similarly found in dry structure or non-associated with oil gas fields. At first, when the prime target was the creation of oil, the gas was by and large saw as an aggravation and was frequently wasted and flared off. Lamentably, some huge measures of gas are as yet being flared when the gas can't be adequately used privately, pumped once more into wells to upgrade oil recuperation, or transported to potential markets by means of pipelines over long separations.

Natural gas has been known since ancient times, mainly through its fires following its ignition when it escaped through fractures and fissures in the earth. Its industrial exploitation began mainly in the 19th century. It was used initially for street lighting and domestic heating.

Rapid progress has been made worldwide in recent years in the discovery of new natural gas deposits and its transportation over the globe, both as a gas and in its cryogenic liquid state, liquefied natural gas (LNG). Its increased availability, the need to meet increasingly lower emission controls, and its relatively low cost have tended to increase its usage as a fuel in a wide variety of applications. The gas has been increasingly viewed as a premium fuel that is in much demand, and may well be for quite some time in the future a prime source of usable fuel energy. (Karim, Dual Fuel Diesel Engine, 2015)

2.1.1. Natural Gas as Fuel

Utilizing characteristic gas as fuel on ship have effectively demonstrated to decreasing the emanation of fumes gas, however it could degrade the engine power and performance. There are a few approach to utilizing characteristic gas as fuel, there are:

- Use existing diesel engines (Dual fuel engines)
- Natural gas engines

Utilizing existing diesel motors just appears to be applicable for retrofit ventures. These are not so likely to occur for LNG projects due to other requirements for the fuel systems. Indeed, studies of existing ships in comparable services show little improvement with regards to emissions, except for particulates.

Diesel engines will run fine on natural gas – however the environmental benefits are not so obvious. Some methane will pass unburned through the engine (methane slip) contributing to the total greenhouse gas emissions. It will be required to mix an amount of diesel with the gas and the gas must be injected at a high-pressure.

Dual-fuel (DF) engines run on gas with 1% diesel (gas mode) or alternatively on diesel (diesel mode); Combustion of gas and air mixture in Otto cycle, triggered by pilot diesel injection (gas mode), or alternatively combustion of diesel and air mixture in Diesel cycle (diesel mode); Low-pressure gas admission. (Lauridsen, et al., 2010)

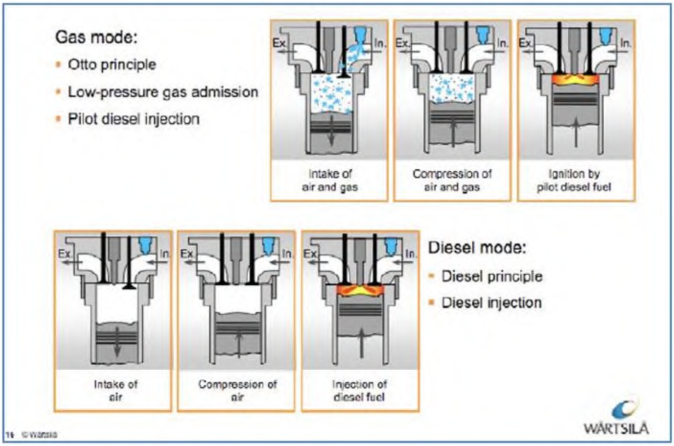


Figure 1 *Combustion on Dual Fuel Engine*

Natural gas engines or spark-ignition gas (SG) engines run only on gas by combustion of gas and air mixture in an Otto cycle, triggered by spark plug ignition. The engines use low-pressure gas admission.

There are four main manufactures of technology that can be used for natural gas powered ships. These four engine manufactures includes Rolls-Royce, GE, Wärtsilä and MAN Diesel.

2.2. Modes Operation of Gas-Fueled Engines

The premixed dual-fuel engine is basically a conventional compression ignition engine of the diesel type where the injection of some liquid fuel, often in quite small dosages, is used to provide the source for ignition. The cylinder charge is made up mainly of lean mixtures of a gaseous fuel and air. There are a number of variations of this mode of operation, such as having the gaseous fuel injected at very high supply pressures directly into the engine cylinder so that the fuel burns into the wake of the earlier injected and already ignited liquid fuel jet. (Karim, Dual Fuel Diesel Engine, 2015)

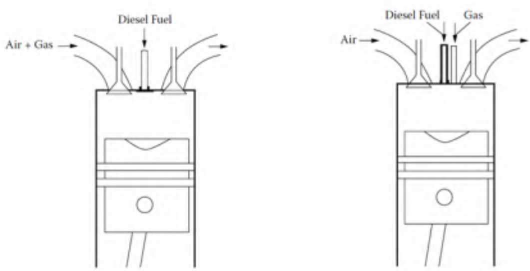


Figure 2 *Schematic representation of a premixed dual-fuel engine with diesel injection to serve as the pilot for ignition (left). Schematic representation of a dual-fuel engine where the fuel gas is injected directly into the chamber and ignition is obtained with pilot fuel injection (right).*

Normally in dual-fuel engine applications, mainly for economic reasons, much of the energy release comes from the combustion of the usually cheaper gaseous fuel, while only a small amount of diesel liquid fuel is injected to provide ignition through timed cylinder injection in the usual way as takes place in conventional diesel engines. Such an operation, with optimum conversion methods, has been shown to have the potential to provide operational characteristics that are often comparable or even superior to those of conventional liquid-fueled diesel or gas-fueled spark ignition engines. This may be achieved while displaying improved emission characteristics and quiet, smooth, and improved low-ambient-temperature operation with reduced thermal loading. Such superior performance may be achieved only when sufficiently effective measures are ensured, such as, for example, the avoidance of knock at high loads and the excessively incomplete gaseous fuel utilization at relatively light loads. Usually, a main aim while retaining alternatively acceptable diesel operation is to maximize the replacement of the diesel fuel by a usually cheaper and more abundant gaseous fuel while maintaining acceptable levels of exhaust emissions and engine performance. (Karim, Dual Fuel Diesel Engine, 2015)

2.3. Structure and Component on Dual Fuel System

The general arrangement of the gas fuel system is shown in figure below. Explanation of the different systems is given in the following sections.

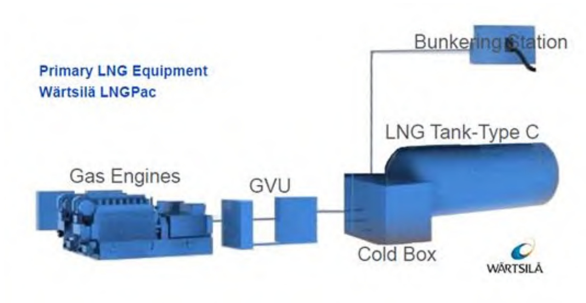


Figure 3 *Ship Natural Gas Fuel System*

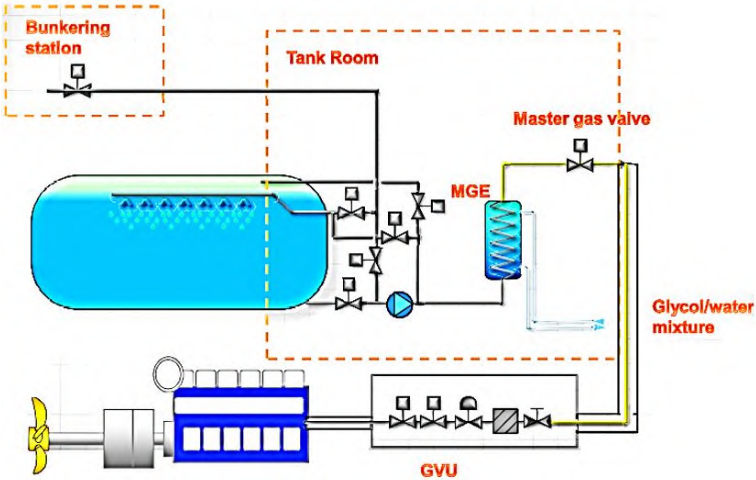


Figure 4 Structure LNG Fuel System by using Pump
Source: Wärtsilä

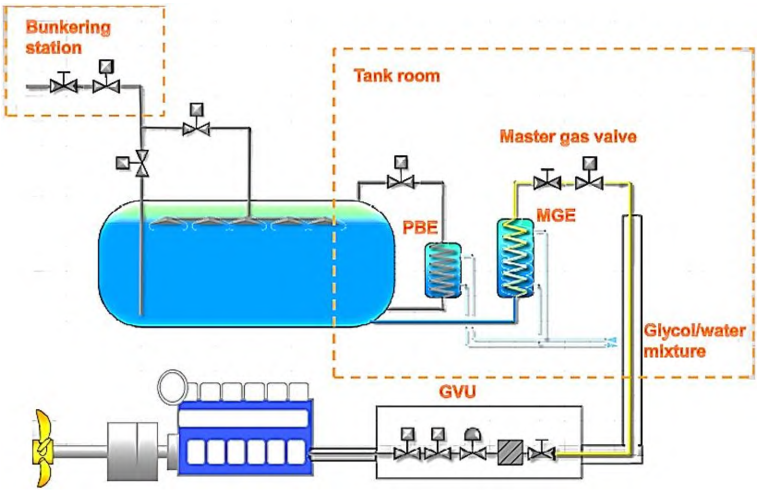


Figure 5 Structure LNG Fuel System by using PBE
Source: Wärtsilä

Components:

- Double skinned tank type-C
- Ventilation Fan
- Cool Box
- Pressure Buildup Evaporator (PBE) or Pump
- Vaporizer (Heat Exchanger)
- Gas Valve Unit
- Inert gas
- Master Gas Valve
- Gas Filter

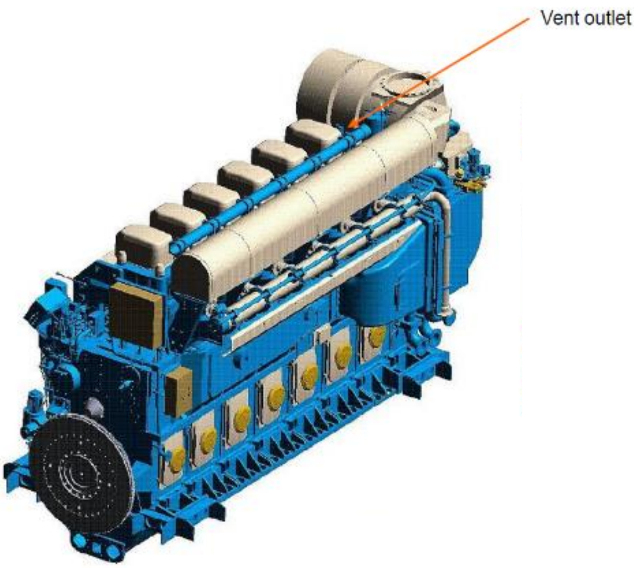


Figure 6 *Vent Outlet on Main Engine*
Source: Wärtsilä

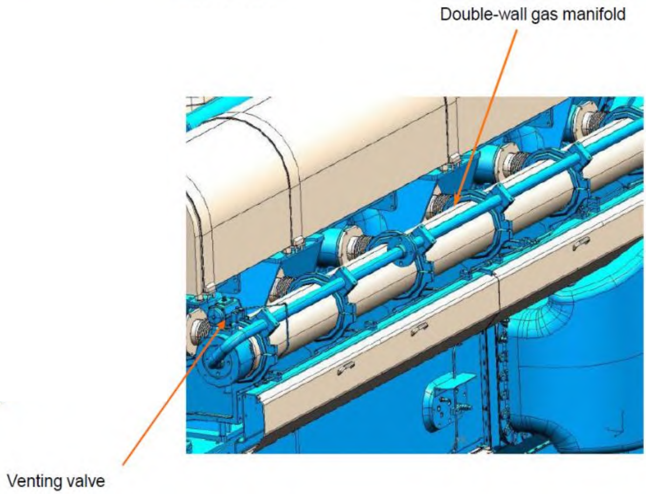


Figure 7 *Double wall gas manifold and venting valve on Main Engine*
Source: Wärtsilä

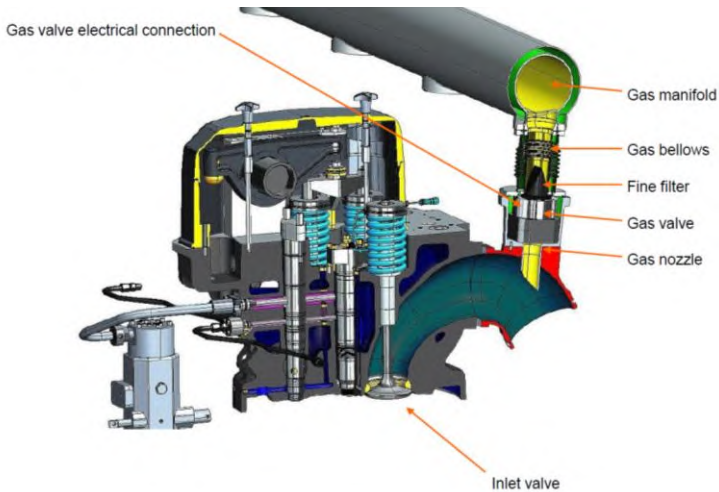


Figure 8 *Gas Fuel System on Main Engine*
Source: Wärtsilä

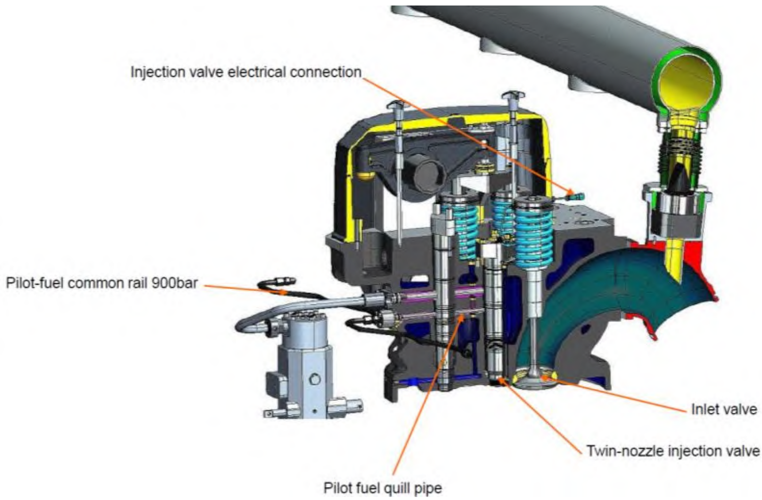


Figure 9 *Pilot Fuel System on Main Engine*
Source: Wärtsilä

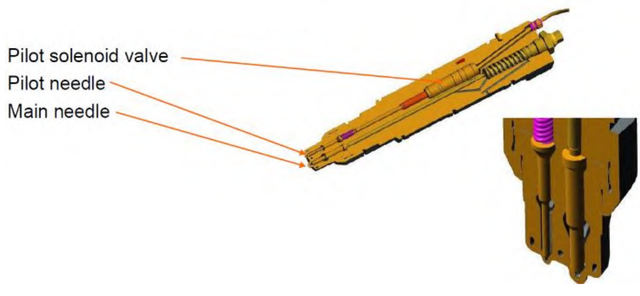


Figure 10 *Pilot Fuel System on Main Engine*
Source: Wärtsilä

The factors to be considered during ship design are (Society for Gas as a Marine Fuel, 2014):

- Protection
  Protection of the LNG storage tank and LNG/ gas pipework from damage through collisions with other vessels and/or cargo or by dropped objects.

- Redundancy
  Redundancy of fuel systems to ensure that the vessel can continue to navigate if one system is damaged or fails.

- Minimization
  Minimization of any hazards provided by the use of gas as fuel.

- Safety
  Safety systems that provide a safe shutdown of hazardous systems and removal of their inventories to prevent the build-up of potentially explosive atmosphere.

2.4. Specific Requirements for Ships Using Natural Gas as Fuel

Specific Requirements for ships which using natural gas as fuel are following requirements from Annex XI and IMO: International Code for Safety of Ships or Other Gases Using Low-Flashpoint Fuels (IGF Code). The basic requirement is the prevention from formation of an explosive atmosphere. The design principle for explosion protection is the application of a double barrier between the fuel gas and the environment. The space between the first and the second barrier is defined as explosion hazardous zone. The space outside of the second barrier is defined as a gas safe area. (MAN B&W, 2015)

To realize this, there are the following two possibilities:
▪ Double walled piping or
▪ Single walled piping installed in a separate compartment
The space between the first and second barrier could be realized as follows:
▪ Gas monitoring and venting of the space or
▪ Gas tight space, monitored and filled with over pressurized inert gas

The protection and certification requirements on components used in explosion hazardous areas are related to the explosion hazardous zones in which they are used. The definitions according to IEC 60079-10: 2008 are:

Zone 0 : area in which an explosive gas atmosphere is present continuously or is present for long periods.
Zone 1 : area in which an explosive gas atmosphere is likely to occur in normal operation.
Zone 2 : area in which an explosive gas atmosphere is not likely to occur in normal operation and, if it does occur, is likely to do so only infrequently and will exist for a short period only.

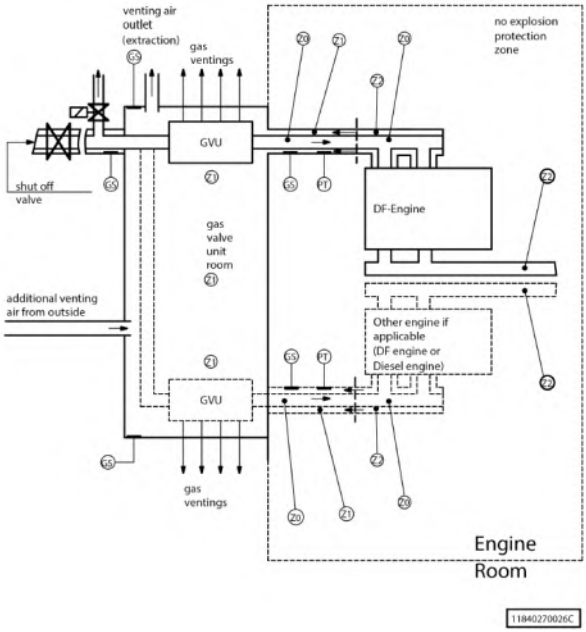


Figure 11 Example of Hazardous area on Engine Room
Source: MAN B&W

2.4.1. Gas Fuel Storage

Fuel tank technology is also available providing several options of fuel tank types. These tanks are double-wall for providing efficient insulation in different ways. LNG is stored in the tanks as a 'boiling cryogen' which is a very cold liquid at its boiling point. However, as efficient as the tank may be, it will not keep the LNG cold enough to remain liquid by itself. As heat is transferred, the pressure in the tank rises as LNG starts evaporating. Under this condition, the gas that boils off needs to be released from the tank in order to control the pressure rates within the tank. As LNG evaporation cannot be reduced, specialized pressurized tanks can be used to store LNG fuel in order to minimize the need for venting as they can withstand a higher internal pressure and thus increase the time between venting events. However, for the LNG fuelled vessels, where LNG is steadily being withdrawn from the tank to power the engines the pressure can be kept below the venting threshold and actually avoid the need of gases to be released. (Lowell, Wang, & Lutsey, 2013)

The boil off gases can likewise be re-liquefied and come back to the tank or to be utilized for the auxiliary engines. Refer to (Würsig, 2013) there are two ways to divide tank type. The first one is according to their shape and then based on their location. The LNG tanks can be located either on the deck or in a tank room within the ship. The most common fuel tank is cylindrical with vacuum insulation.

The current administrative methodology depends on self-supporting tanks as characterized in the IMO IGC code: type A (designed as ship structures) and type B (prismatic or spherical) tanks are generally feasible for fuel gas tanks but their requirement for pressure maintenance and secondary barrier raise problems which have not yet been solved in a technically and commercially sound way. This may be a future solution for ships carrying large amounts of LNG as fuel. Hence IMO type C tanks (pressure vessels) turn out to be the preferred solution for current designs. (Boulougouris & Chrysinas, 2015)

In this point, it can be examined the second way of division between tank types as it is obvious below. As a result according to this second way, there are two types of gas storage tanks on the vessel:

- The Membrane Tanks
- The Independent Tanks

2.4.1.1. Membrane Tanks

Membrane tanks use the available space efficiently but require a secondary barrier in the event of a gas leak. Furthermore, they are reinforced with a nitrogen system and a gas detector for each separate insulated space. (American Bureau of Shipping, 2011)

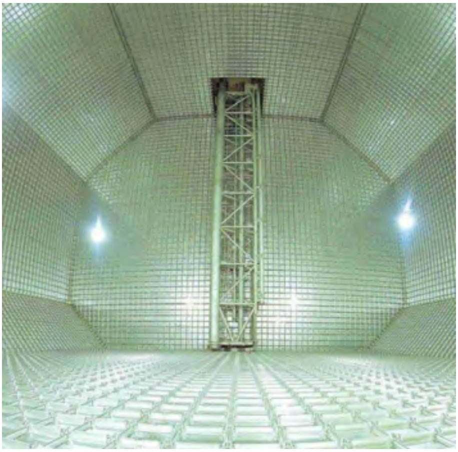


Figure 12 *Membrane Tank*
Source: ABS

2.4.1.2. Independent Tanks

There are three types of independent tanks:

- Type A
- Type B
- Type C (pressurized tanks)

The usage of this type of tanks is suitable for higher volumes of LNG. It is an atmospheric tank which is adjustable to hull shape and it is space efficient. However, it is not common to be used by LNG fuelled vessels as Type A tanks require a full secondary barrier to prevent potential release of the liquefied gas in the event of a tank failure. Another obstacle is also the price of Type A tanks that is very high. (American Bureau of Shipping, 2011)

For high capacity, appropriate Type B independent tanks are required. According to the IGC Code, the tank must be arranged so that it can be possible to provide compressed inert gas to have a secondary barrier and provide adequate protection to the steel in case of gas leak. The pressurized inert gas consists of dry air and the inert gas filling. (Würsig, 2013)

Refer to (Würsig, 2013), the independent tanks type C is the most common, as mentioned earlier, because they are manufactured for low capacity. Their main characteristic is the high pressure gas, approximately 5 bar, and a maximum allowable working pressure of 20 bar. This allows the provision of directly on machines, without having gone through pumps.

2.4.1.3. LNG Tank Location

There are two conceivable outcomes, above or below deck, the above deck location is less mind boggling and less costly. The below deck location requires zoned division from different spaces, explosion proof appliance, devoted ventilation system, in general, more controls. LNG tank storage cannot be placed where MDO can be stored (wing tanks, DB’s) and thus the volume requirements are many times that of storing MDO. On the other hand, above deck locations, well away from the vessels roll and pitch centers, invite greater sloshing and possibly greater structural weight in the installation.

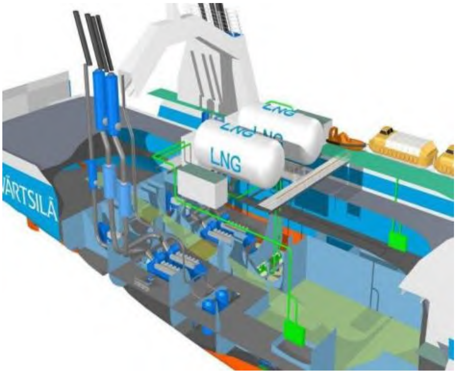


__Figure 13__ LNG Tank Location above the Deck
Source: Wärtsilä

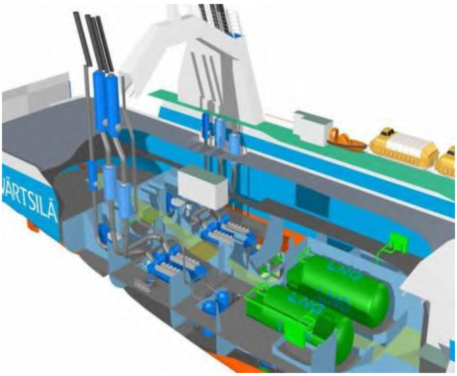


__Figure 14__ LNG Tank Location below the Deck
Source: Wärtsilä

The tanks that will be installed on open deck have the following limitations. (American Bureau of Shipping, 2011)

- Have B/5 distance from the hull as mentioned earlier. In ships not carrying passengers, the tanks can be placed closer to the edge of the deck. This depends on the volume of the tank and ranged from 0.8-2.0 m but never less than 800mm.

- To be located in a place where there is adequate natural ventilation.

The tanks to be installed indoors must follow the following rules (American Bureau of Shipping, 2011):

- Maximum air pressure 10 bar
- Be located within B / 5 or 11.5 m from the hull.
- Have B/15 distance or 2 m from the bottom. In ships not carrying passengers, the tanks can be placed closer to the edge of the deck. This depends on the volume of the tank and ranged from 0.8-2.0m but never less than 800mm.

2.4.1.4. Management of Boil off Gas (BOG)

A critical aspect of controlling methane leak emissions is the management of boil-off gas (BOG) from the cryogenically cooled liquefied natural gas. At atmospheric pressure, natural gas must be maintained at a temperature below –162°C in order to stay in a liquid state. It is therefore stored and transported throughout the supply chain in specially designed, well-insulated containers. No matter how well insulated, however, some heat will continually seep into the container. As heat is absorbed, the head space pressure inside the container rises as LNG evaporates. The rate at which LNG evaporates depends on the size of the tank and the materials and methods of construction. (Boulougouris & Chrysinas, 2015)

LNG capacity tanks are intended to vent some of the vaporized gas when the internal tank pressure rises above a set threshold. Many LNG storage tanks are designed to function in range close to atmospheric pressure, and they generally vent when the internal tank pressure rises above approximately 10 pounds per square inch gauge, or psig (0.7 bar). If LNG must be stored for long periods, a pressurized Type C tank may be used to extend the amount of time without resorting to venting. The use of a pressurized tank does not reduce the LNG evaporation rate, but it increases the time between venting events because it can withstand a higher internal pressure. (Harperscheidt, 2011)

There are four main methods for dealing with the BOG created during LNG storage and handling: (1) releasing it to the atmosphere; (2) flaring it; (3) capturing it for use as gaseous fuel, or (4) capturing and reliquefying it. Capture of BOG can take a number of forms. For marine vessels that store LNG onboard for their own propulsion, BOG is continually being created in the fuel tanks as heat is absorbed, but liquid and vapors are also steadily being withdrawn from the tank to power the engines.

2.4.1.5. Filling Limits

Other than the way that LNG tanks require additional volume because of low density of LNG and the tank's shape and insulation, some tank volume is required to be reserved for LNG expansion and for residual LNG (heel) in the empty tank to keep it cold. The tank's relief valve pressure drives the limit placed on the loading level. The reason for this is that LNG's density decreases quickly as heat is absorbed, and its temperature and saturation pressure increase. The higher the temperature (and corresponding saturation pressure), the lower the density.

Current IMO regulations limit LNG tanks to 98% full at the relief valve setting where it is the maximum allowable volume. Loading a tank with LNG at -162^{o}C, when it is close to atmospheric pressure, is the desirable loading condition because at that condition LNG can remain in the tank for the longest period of time before heat absorption raises the tank pressure to the relief valve setting. At this initial loading condition, the LNG density will be at its highest value. (Harperscheidt, 2011)

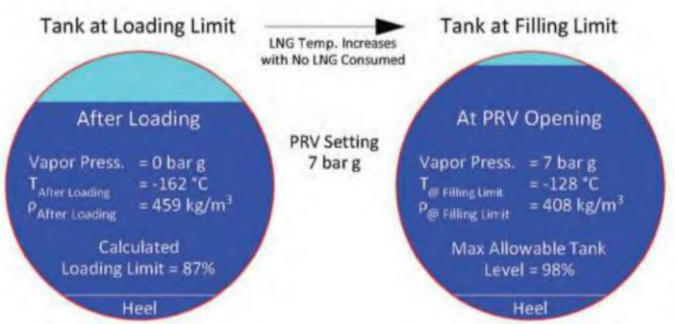


Figure 15 *Loading limits for a range of relief valve pressure*
Source: Bunkering, Infrastructure, Storage and Processing LNG,

Since the mass of LNG remains the same as the pressure is building and the LNG density is going down (raising the level in the LNG tank), the ratio of the densities between the LNG when bunkered and when at the 98% full limit determines the loading limit (the level the tank can be loaded while bunkering).

The higher the relief valve pressure the lower the loading limit, but on the other hand, the higher the relief valve pressure, the longer the LNG can stay in the tank. Besides the limit on filling, usable tank capacity is further reduced by the common practice of leaving LNG in the bottom 5% of the tank volume to continue boiling off, keeping the tank cold until the next bunkering. Cooling down an empty, warm tank before it can be refilled with LNG takes a long time and is normally avoided.

The bottom line is that usable capacity of LNG in a Type C pressure tank is only about 80% to 85% of its available volume, depending on the relief valve setting. All range calculations for the vessel should be based on the usable capacity and not the highest filling or loading limits. Except from the naval architecture perspective, there is much to learn when considering the use of LNG as ship's fuel, particularly those related to LNG fuel storage. Engine selection, bunkering, maintenance, operation, and training also need to be considered and each adds to the complexity of the switch to LNG fuel. (Harperscheidt, 2011)

2.4.2. Engine Room

The engine room is considered as a gas safe area due to the complete double wall fuel gas piping system on the engine and in the engine room. Additionally each engine room must be equipped with at least two intrinsically safe certified gas sensors of continuous monitoring type. One intrinsically safe certified gas sensor in the ventilation outlet and one intrinsically safe certified gas sensor above each DF engine. The detection equipment shall be located where gas may accumulate. The number of detectors could depend on size, layout and ventilation of the engine room, and has to be agreed by the classification society. (Wärtsilä, 2014)

2.4.3. Gas Fuel Piping on the Engine

The fuel gas supplied to the engine is provided to the cylinders individually through the gas admission valves mounted in the air inlet manifold of each cylinder. The gas admission valves are controlled individually by the speed governor in order to regulate the engine power and speed through controlling the amount of fuel gas fed to each cylinder. (Wärtsilä, 2014)

The design of the gas admission valves and piping ensures that under normal conditions, only air and not fuel gas is contained in the charge air manifold. The gas admission valves are actuated (opened) through solenoids and are closed through springs (normally closed type).

2.4.4. Gas Fuel Piping Between GVU Room and Engine

Before the gas is supplied to the engine it passes through a Gas Valve Unit (GVU). The GVU include a gas pressure control valve and a series of block and bleed valves to ensure reliable and safe operation on gas. The pipe between the gas valve unit (GVU) room and the engine is a double walled pipe, also the compensator used to connect the engine is double walled. The space in between the inner and outer pipe of the double walled pipe is continuously ventilated by 30 air changes per hour. (MAN B&W, 2015)

The piping is designed to withstand an internal explosion without being untight. A non-dangerous deformation of the components is permissible. Ductile material has to be used. Therefore, piping with pressure rating PN40 (40 bar), valves with pressure rating PN25 (25 bar) and compensators with pressure rating PN10 (10 bar) are used. In a gas line with 5 bar operation pressure, the maximum explosion pressure for Methane is 36 bar. (MAN B&W, 2015)

The unit includes a manual shut-off valve, inerting connection, filter, fuel gas pressure control valve, shutoff valves, ventilating valves, pressure transmitters/gauges, a gas temperature transmitter and control cabinets. The filter is a full flow unit preventing impurities from entering the engine fuel gas system. The fineness of the filter is 5 μm absolute mesh size. (Wärtsilä, 2014)

The pressure drop over the filter is monitored and an alarm is activated when pressure drop is above permitted value due to dirty filter. The fuel gas pressure control valve adjusts the gas feed pressure to the engine according to engine load. The pressure control valve is controlled by the engine control system. The system is designed to get the correct fuel gas pressure to the engine common rail pipe at all times. Readings from sensors on the GVU as well as opening and closing of valves on the gas valve unit are electronically or electro-pneumatically controlled by the GVU control system. All readings from sensors and valve statuses can be read from Local Display Unit (LDU). The LDU is mounted on control cabinet of the GVU. (Wärtsilä, 2014)

2.4.5. Gas Valve Unit

The fuel gas pressure supplied to the dual-fuel engine is regulated and controlled individually by one gas valve unit (GVU) for each dual-fuel engine. The GVU has to be protected against excessive inlet overpressure by an external safety valve (to be mounted upstream of the shut-off valve, e.g. downstream of the gas compressor).

The gas valve unit has the following functions:

- Gas leakage test through engine control systems before engine start.
- Control of gas feed pressure to dual-fuel engine.
- At the end of gas operation, the unit shuts off the gas supply.
- Shut-off of the fuel gas supply in case of emergency stop.
- Automatic purging of gas distribution after DF operation incl. emergency stop with inert gas.
- Purging for maintenance reasons with inert gas.

If the engine is not in operation, the manual gas shut-off valve at the inlet of the GVU, or another shut-off valve nearby upstream of the GVU, has to be closed. There must not be any gas present downstream of the manual shut-off valve of the GVU if the engine is not in operation. (Wärtsilä, 2014)

Installation of GVU (Wärtsilä, 2014):

- Installation of gas valve unit in dedicated compartment (GVU room) with gas-tight walls.
- Single wall gas pipes and instrumentation in the gas valve unit room.
- The gas valve unit room has to be ventilated by 30 air changes per hour. The ventilation system of the GVU room consists of exhaust ventilators installed in a dedicated exhaust air duct. Ventilation air for the GVU room will be sucked in from outside and will also come from the engine room via the double wall pipe. Therefore, the air pressure in the GVU room has to be constantly lower than the air pressure in the engine room. The difference of pressure has to be monitored.
- The volume of the gas valve unit room has to be as small as possible. Maintenance work must be possible.

- The GVU room has to be monitored by at least one intrinsically safe certified gas sensor. The exact number of gas sensors to be agreed with the authority and according to the room geometry.
- A gas overpressure safety valve has to be installed upstream of the GVU.

2.4.6. Ventilation

Rooms and spaces to be ventilated for gas leakage fighting reasons:

- GVU room
- Space between the double wall gas pipes

Technical requirements of the ventilation (Wärtsilä, 2014):

- The complete design of the ventilation system for a gas engine driven new building has to be in accordance with applicable marine rules (IGF Code and IGC Code etc.) and approved by the marine classification society.
- The design of the ventilation is in general a mechanical forced ventilation system.
- Ventilation air is taken from free atmosphere and gas safe area via ducting.
- Ventilation inlet and outlet duct have to be equipped with automatically closing fire louvers and are mechanically protected by screens with not more than 13 mm square mesh.
- Ventilation capacity: For hazardous areas min. 30 air changes per hour. Monitoring of the suction with alarm below 30 air changes per hour.

- This ventilation capacity may be reduced to 10 air changes per hour provided automatic filling of the duct with nitrogen upon detection of gas is arranged for.
- Indication and alarming of loss of ventilation capacity in engine control station.
- Ventilation system independent from other ventilation systems.
- Independent systems for each engine room. Each GVU room will be forced exhaust ventilated.
- Ventilation is in operation even under shutdown conditions.
- Ventilation fans have to be approved for ventilating explosive atmosphere.
- Ventilation air outlet kept away from ignition sources.
- Inlet and outlet equipped with closing arrangement (louvers) in case of fire in engine or GVU room.

2.4.7. Gas Detectors

The project related requirements have to be in accordance with applicable marine rules (IGF Code and IGC Code etc.) and approved by the marine classification society.

General requirements:

- Each engine room must be equipped with at least two intrinsically safe certified gas sensors of continuous monitoring type. One intrinsically safe certified gas sensor in ventilation outlet and one intrinsically safe certified gas sensor above each DF engine, where gas may accumulate.
- The GVU room ventilation outlet must be monitored at least by additional one intrinsically safe certified gas sensor.

- Gas sensors are to be connected to a common alarm system with audible and visible alarms.
- Gas sensors have to be of intrinsically-safe and certified type and have to be type approved by IACS classification societies.
- Two independent, continuous working, fixed gas monitoring systems in operation when gas fuel is in piping or during purging.
- Gas detection requirements: Self-monitoring.
- Self-detection of system: Malfunction shall not lead to false emergency shutdown of the engine.
- Functional redundancy when either one of the systems fails.
- System designed to be readily tested.

2.5. Risk Assessment

Risk assessment can be facilitated through several formal techniques. These different methods may contain comparable ways to deal with answer the basic risk assessment questions; however, a few methods might be more fitting than others for risk analysis depending on the situation.

Risk assessment techniques develop processes for identifying risk on the system, it will divided into two general categories: induction and deduction.

Induction provides the reasoning of a general conclusion from individual cases. Inductive analysis answers the question, “what are the system state(s) due to some event?” In reliability and risk studies this “event” is often some fault in the system. Deductive approaches provide reasoning for a specific conclusion from general conditions. This technique attempts to recognize what methods of a framework/subsystem failure can be used to contribute to the failure of the system. Deductive logic answers the question, “how can a system state occur?”. (Wilcox, Burrows, Ghosh, & Ayyub, 2000)

2.5.1. HAZOP Method

Hazard and Operability or HAZOP is an analysis technique which used to exam safety factor on new system or modification to knowing the potential failure on their operability. The HAZOP study should preferably be carried out as early in the design phase as possible - to have influence on the design.

Refer to HAZOP studies – Application guide (Norhayati, 2001), HAZOP may also be used more extensively, including:

- At the initial concept stage when design drawings are available.
- When the final piping and instrumentation diagrams (P&ID) are available.
- During construction and installation to ensure that recommendations are implemented.
- During commissioning.
- During operation to ensure that plant emergency and operating procedures are regularly reviewed and updated as required.

The basis of HAZOP is a “guide word examination” which is a conscious quest for deviations from the design intent. To encourage the examination, a framework is partitioned into parts in the design intent for every part can be sufficiently characterize. The size of the part chosen is likely to depend on the complexity of the system and the severity of the hazard. In complex frameworks or those which show a high risk the parts are prone to be small.

The design intent for a given part of a framework is expressed regarding elements which pass on the essential features of the part and which represent natural divisions of the part. The selection of elements to be analyzed is to some degree a subjective choice in that there might be several combinations which will accomplish the required reason and the decision may also depend upon the particular application. Elements may be discrete steps or stages in a procedure, individual signals and equipment items in a control system, equipment or components in a process or electronic system, and so forth. (Norhayati, 2001)

The identification of deviations from the design intent is achieved by a questioning process using predetermined “guide words”. The role of the guide word is to stimulate imaginative thinking, to focus the study and elicit ideas and discussion, thereby maximizing the chances of study completeness.

Table 1 *Basic Guide Words and Meanings*

Guide Word	Meaning
NO or NOT	Complete negation of the design intent
MORE	Quantitative increase
LESS	Quantitative decrease
AS WELL AS	Qualitative modification/ increase
PART OF	Qualitative modification/ decrease
REVERSE	Logical opposite of the design intent
OTHER THAN	Complete substitution

Table 2 Guide Words relating to Clock Time and Order or Sequence

Guide Word	Meaning
EARLY	Relative to the clock time
LATE	Relative to the clock time
BEFORE	Relating to order and sequence
AFTER	Relating to order and sequence

Some examples of combinations of guide-words and parameters:

- NO FLOW
  Wrong flow path - blockage - incorrect slip plate – incorrectly fitted return valve - burst pipe - large leak - equipment failure- incorrect pressure differential - isolation in error.

- MORE FLOW
  Increase pumping capacity - increased suction pressure - reduced delivery head - greater fluid density - exchanger tube leaks - cross connection of systems - control faults.

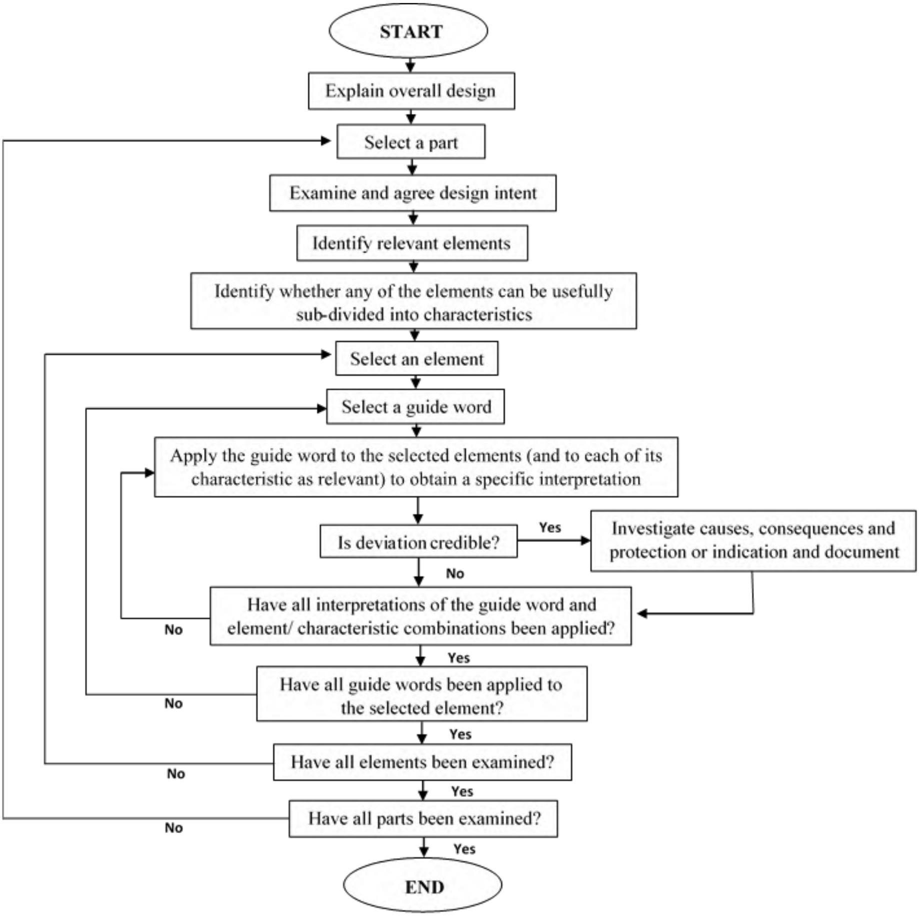


***Figure 16** Flow chart of the HAZOP examination procedure – Element first sequence*
Source: HAZOP Studies – Application Guide

A worksheet to record the results of examinations and follow-up should be produced or received. Despite the reporting choice received, the worksheet ought to contain the fundamental components to suit specific requirements. The layout of the worksheet will vary depending upon whether it is a part of a manual or computerized reporting program. The manually completed form will normally consist of a header and columns.

The header may contain the following information: project, subject of the study, design intent, part of the system being examined, members of the team, drawing or document being examined, date, page number, etc.

The headings (titles) of the columns may be as follows:

- for those completed during the examination:
    - reference number;
    - element;
    - guide word;
    - deviation;
    - cause;
    - consequences;
    - action required.

Additional information such as safeguards, severity, comments and risk ranking may also be recorded.

- for those completed during the follow-up:
    - recommended action;
    - priority/risk ranking;
    - responsibility for action;
    - status;
    - comments.

Study title:							Page: of		
Drawing no.:			Rev no.:				Date:		
HAZOP team:							Meeting date:		
Part considered:									
Design intent:			Material: Source:		Activity: Destination:				
No.	Guide-word	Element	Deviation	Possible causes	Conse-quences	Safeguards	Comments	Actions required	Action allocated to

Figure 17 *HAZOP Worksheet BS IEC 61882*

Refer to (Rausand, 2005) the description of content on the Figure 17, are:

- Design Intent
  The design intent is a description of how the process is expected to behave at the node; this is qualitatively described as an activity (e.g., feed, reaction, sedimentation) and/or quantitatively in the process parameters, like temperature, flow rate, pressure, composition, etc.

- Deviation
  A deviation is a way in which the process conditions may depart from their design/process intent.

- Parameter
  The relevant parameter for the condition(s) of the process (e.g. pressure, temperature, composition).

- Guideword
  A short word to create the imagination of a deviation of the design/process intent. The most commonly used set of guide-words is: no, more, less, as well as, part of, other than, and reverse. In addition, guidewords like too early, too late, instead of, are used; the latter mainly for batch-like processes. The guidewords are applied, in turn, to all the parameters, in order to identify unexpected and yet credible deviations from the design/process intent.

- Cause
  The reason(s) why the deviation could occur. Several causes may be identified for one deviation. It is often recommended to start with the causes that may result in the worst possible consequence.

- Consequence
  The results of the deviation, in case it occurs. Consequences may both comprise process hazards and operability problems, like plant shut-down or reduced quality of the product. Several consequences may follow from one cause and, in turn, one consequence can have several causes

- Safeguard
  Facilities that help to reduce the occurrence frequency of the deviation or to mitigate its consequences. There are, in principle, five types of safeguards that:
  1. Identify the deviation (e.g., detectors and alarms, and human operator detection)
  2. Compensate for the deviation (e.g., an automatic control system that reduces the feed to a vessel in case of overfilling it. These are usually an integrated part of the process control)
  3. Prevent the deviation from occurring (e.g., an inert gas blancket in storages of flammable substances)
  4. Prevent further escalation of the deviation (e.g., by (total) trip of the activity. These facilities are often interlocked with several units in the process, often controlled by computers)
  5. Relieve the process from the hazardous deviation (e.g., pressure safety valves (PSV) and vent systems)

2.5.2. Risk Evaluation

The risk evaluation is represented by the achievement of a synthetic level of risk, which is the “magnitude of a risk or combination of risks, expressed in terms of the combination of consequences and their likelihood”. This level of risk should be compared with risk criteria for determining if the risk is acceptable or tolerable. Evaluating risks is important for determining priorities for the implementation of risk control measures. The risk rating is a combination of the frequency (F) and the likelihood of the incident occurring and the severity of the possible consequences (C). (ISO (Intenational Organization for Standardization), 2009)

On evaluate risk, there is a point which must know to determine criteria for the risk. This is will be a reference to know the criteria of the risk, tolerable, intolerable or ALARP (As Low As Reasonably Practicable). There for it will be need a standard as a reference to determine their criteria, some standard well most known are DNV-GL, NASA, US Coast Guard, US Department of Defense, UK HSE, IMO, etc. There are also several standard which made by company for their risk evaluation. For risk evaluation on this Bachelor Thesis will be use risk matrix from MICOPERI Marine Contractors which has applied on risk assessment of LNG Marine Fuel by Mystic River Partners LLC (LNG Marine Operation Consultants).

MICOPERI Risk Matrix			PROBABILITY				
			1	2	3	4	5
			Very Unlikely	Unlikely	Possible	Likely	Frequent
SEVERITY	1	Minor	1	2	3	4	5
	2	Moderate	2	4	6	8	10
	3	Significant	3	6	9	12	15
	4	Serious	4	8	12	16	20
	5	Catastrophic	5	10	15	20	25

Figure 18 *MICOPERI Risk Matrix*

Table 3 *Severity Description*

Rank	Description
1	Minor: Minor injury/ no internal disruption.
2	Moderate: Injury which requires medical attention/ minor internal disruption.
3	Significant: Potentially life threatening injury causing temporary disability and/or requiring medevac/ disruption possibly requiring corrective action.
4	Serious: Major life threatening injury or causing permanent disability/ incomplete recovery/ pollution with significant impact/ very serious disruption which may cause performance degraded.
5	Catastrophic: Fatality or multiple fatalities or multiple life threatening injuries causing permanent disabilities/ total loss.

Table 4 *Probability Description*

Rank	Description	Probability
1	Very Unlikely: Could only occur under a freak combination of factors.	$< 10^{-5}$
2	Unlikely: May occur only in exceptional circumstances.	$10^{-5} – 10^{-4}$
3	Possible: Could occur at some time.	$10^{-4} – 10^{-2}$
4	Likely: Would not require extraordinary factors to occur at some time.	$10^{-2} – 10^{-1}$
5	Frequent: Almost certain to happen if conditions remain unchanged.	$10^{-1} – 1$

Where:

1-2	: Low risk area, the potential hazards are under control.
3-8	: Moderate risk area, there is the need to verify that the potential hazards are under control and improve the measures already adopted.
9-15	: Medium risk area, there is the need to identify and schedule protection and prevention measures to be adopted in order to reduce or the probability P or the potential damage S.
16-25	: High risk area, there is the need to identify and schedule protection and prevention measures to be adopted in order to reduce the probability of the potential hazard (they shall be considered as urgent).

2.5.3. Frequency and Consequence Analysis

Frequency analysis involves estimating the likelihood of occurrence of each failure case. There are several main approaches to estimating frequencies:

- Historical accident frequency data. This uses previous experience of accidents. It is a simple approach, relatively easy to understand, but is only applicable to existing technology with significant experience of accidents and where appropriate records have been kept.

- Fault tree analysis. This involves breaking down an accident into its component causes, including human error, and estimating the frequency of each component from a combination of generic historical data and informed judgment.

- Event tree analysis. This is a means of showing the way an accident may develop from an initiating event through several branches to one of several possible outcomes. The technique is usually used to extend the initiating event frequency estimated by one of the above means into a failure case frequency suitable for combining with the consequence models.

Frequencies are simply calculated by combining accident experience and population exposure, typically measured in terms of installation-years:

Event frequency per installation per year

$$= \frac{\text{Number of Instalation x Years of Exposure}}{\text{Number of Events}}$$

A prime source of data for frequency analysis on this Bachelor Thesis is the Offshore and Onshore Reliability Data (OREDA). The data from OREDA are used as value of basic event for FTA.

Taxonomy no 4.3.2.3		Item Control and Safety Equipment Valves Butterfly Oil systems								
Population	Installations	Aggregated time in service (10^6 hours)					No of demands			
		Calendar time *			Operational time †					
2	1	0.0985			0.0716					
Failure mode	No of failures	Failure rate (per 10^6 hours).					Active rep.hrs	Repair (manhours)		
		Lower	Mean	Upper	SD	n/τ		Min	Mean	Max
Critical	1* 1†	**0.51** **0.70**	**10.15** **13.96**	**48.15** **66.26**	**10.15** **13.96**	**10.15** **13.96**	**2.0**	**2.0**	**2.0**	**2.0**
Fail to regulate	1* 1†	0.51 0.70	10.15 13.96	48.15 66.26	10.15 13.96	10.15 13.96	2.0	2.0	2.0	2.0
Degraded	1* 1†	**0.51** **0.70**	**10.15** **13.96**	**48.15** **66.26**	**10.15** **13.96**	**10.15** **13.96**	**4.0**	**4.0**	**4.0**	**4.0**
External leakage - Utility medium	1* 1†	0.51 0.70	10.15 13.96	48.15 66.26	10.15 13.96	10.15 13.96	4.0	4.0	4.0	4.0

Figure 19 *Example Data Record from OREDA 2002*

Fault Tree Analysis (FTA) is an analysis technique that models possible combinations among system elements, such as equipment failures, human errors, and external events and conditions leading to specific accidents. The FTA technique relies on the backward search method employing logic tree (Boolean logic) of the relationships. The technique shows how hazard events can occur through the escalation of a single or a combination of a wide range of latent initiating events. It also shows the safeguards in place and how they can fail to prevent escalation of events. The FTA technique is applicable for any risk analysis, but it is used most effectively to analyses accidents or problems that are characterized by a large number and complex combinations of events. It can be used as a tool to understand causal factors and determine actual root causes of accidents. (Mullai, 2006)

The tree structure is deemed sufficient to demonstrate the ways in which events arise. A list of recommendations is also developed for managing risks. The main elements most commonly used to construct a fault tree are (Mullai, 2006):

- The top event is the one that is analyzed, which is represented by a rectangle;
- Intermediate events are system states or occurrences that contribute to the accident, which are represented by rectangles;
- Basic events are the lowest levels of resolution in the fault tree, which are represented by circles;
- Undeveloped events are those that are not further developed in the fault tree, which are represented by diamonds;
- “AND” gates - the output event associated with this gate exists only if all of the input events exist simultaneously;

- "OR" gates - the output event associated with this gate exists if at least one of the input events exists.

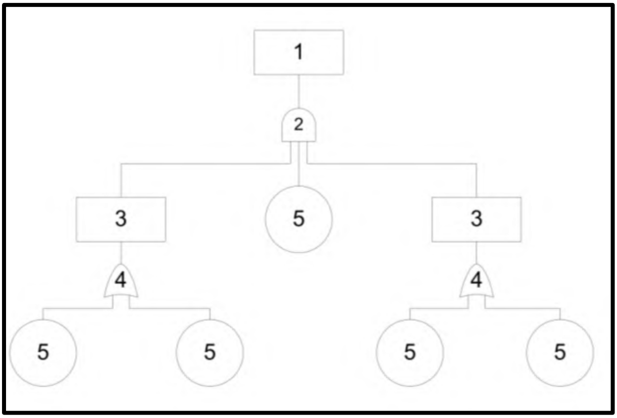


Figure 20 Steps in Fault Tree Analysis

1. Identify undesirable top event.
2. Link contributors to top event by logic gates (Example shape of AND Gate).
3. Identify first level contributors.
4. Link second level contributors to top by logic gates (Example shape of OR Gate)
5. Basic event.

OR Gate, either of two independent element failures produces system failure.

$R_T = R_A R_B$
$P_F = 1 – R_T$
$P_F = 1 – (R_A R_B)$
$P_F = 1- [(1-P_A) (1-P_B)]$
$P_F = P_A + P_B - P_A P_B$

$P + R = 1$
$R = e^{-\lambda T}$
$P = 1 - e^{-\lambda T}$

R: Reliability
P: Failure Probability
λ: Failure Rate
T: Exposure Interval

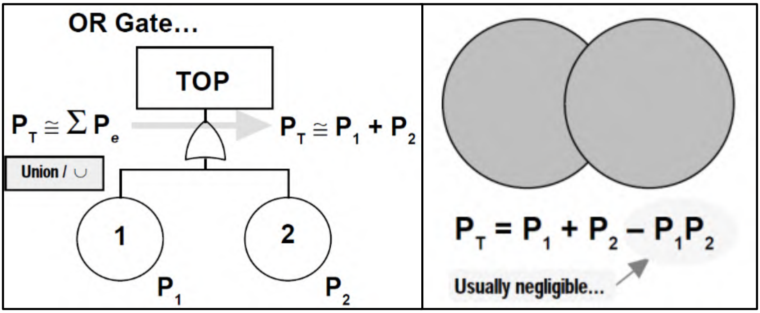


Figure 21 *Propagation through OR Gate*
Source: Fault Tree Analysis, 4th Edition

AND Gate, both of two independent elements must fail to produce system failure.

$R_T = R_A + R_B - R_AR_B$
$P_F = 1 - R_T$
$P_F = 1 - (R_A + R_B - R_AR_B)$
$P_F = 1- [(1-P_A) + (1-P_B) - (1-P_A)(1-P_B)]$
$P_F = P_AP_B$

$P + R = 1$
$R = e^{-\lambda T}$

$P = 1 - e^{-\lambda T}$

R: Reliability
P: Failure Probability
λ: Failure Rate
T: Exposure Interval

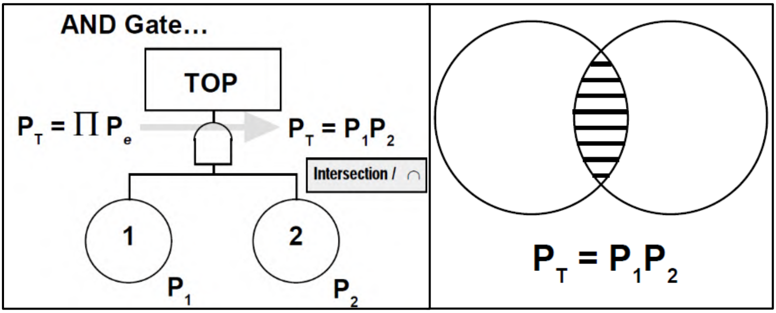


Figure 22 Propagation through AND Gate
Source: Fault Tree Analysis, 4th Edition

Estimation of the consequences of each failure case is necessary to complete the analysis of the risks. The approach usually differs for each type of hazard. For this Bachelor Thesis, consequence analysis will be use ALOHA software to determine consequence which could be arise from all hazard.

2.5.4. Mitigation

If there are any unacceptable risk on the scenario, then those risk will be analysis for mitigation act to reduce the risk. Mitigation analysis method for this Bachelor Thesis is Layers of Protection Analysis.

Layers of protection analysis (LOPA) is a semi-quantitative methodology that can be used to identify safeguards that meet the independent protection layer (IPL). The IPL is capable of detecting and preventing or mitigating the consequences of specified, potentially hazardous event(s), such as a runaway reaction, loss of containment, or an explosion. An IPL is independent of all the other protection layers associated with the identified potentially hazardous event. Independence requires that the performance is not affected by the failure of another protection layer or by the conditions that caused another protection layer to fail. Most importantly, the protection layer is independent of the initiating cause. The protection provided by the IPL reduces the identified risk by a known and specified amount (Summers, 2002).

2.6. Previous Research

The Previous Research about safety assessment of fuel system on dual fuel engine of ship had been done by:

1. Wilcox, Robb. Burrows, Mark. Ghosh, Sujit. Ayyub, Bilal. "Risk-based Technology Methodology for the Safety Assessment of Marine Compressed Natural Gas Fuel Systems", International Cooperation on Marine Engineering System/ The Society of Naval Architects and Marine Engineers, pp. 1-21, New York, May, 2000

The research has focus to determine design safety for novel marine on a CNG fuel system on the KINGS POINTER training vessel by using Risk-based technologies (RBT) which provide techniques to facilitate the proactive evaluation of system safety through risk assessment, risk control, risk management, and risk communication. RBT techniques offer a proactive means for safety management through the identification of hazards and reducing associated risks through risk control measures. These tools provide a formal and systematic way to address safety for novel designs when existing standards are not available to provide safety guidance. Design acceptance should be determined based on system design to adequate levels of safety, which may be qualitatively identified in a risk matrix and/or design guidelines.

CHAPTER III
RESEARCH METHODOLOGY

In order to solve the problem above, that will be used data analysis from literatures.

1. **Background.**
   Before conducting the research, first will be explained the background of this study.

2. **Study of literature.**
   The study of literature is an early stage is the stage of learning about the basic theories to be discussed or used in the thesis. Source taken at this stage comes from books, papers, websites, journals, and so forth.

3. **Data collection.**
   This phase is to obtain information about the ships that use gas fuel and learn the workings of their systems.

4. **Identify Function, Requirements and Specification.**
   Identify and understand the process steps and their functions, requirements, and specifications that are within the scope of the analysis. The goal in this phase is to clarify the design intent or purpose of the process. This step leads quite naturally to the identification of potential failure modes.

5. **Risk Identification (HAZOP)**
   Potential cause of failure describes how a process failure could occur, in terms of something that can be controlled or corrected. The goal is to describe the

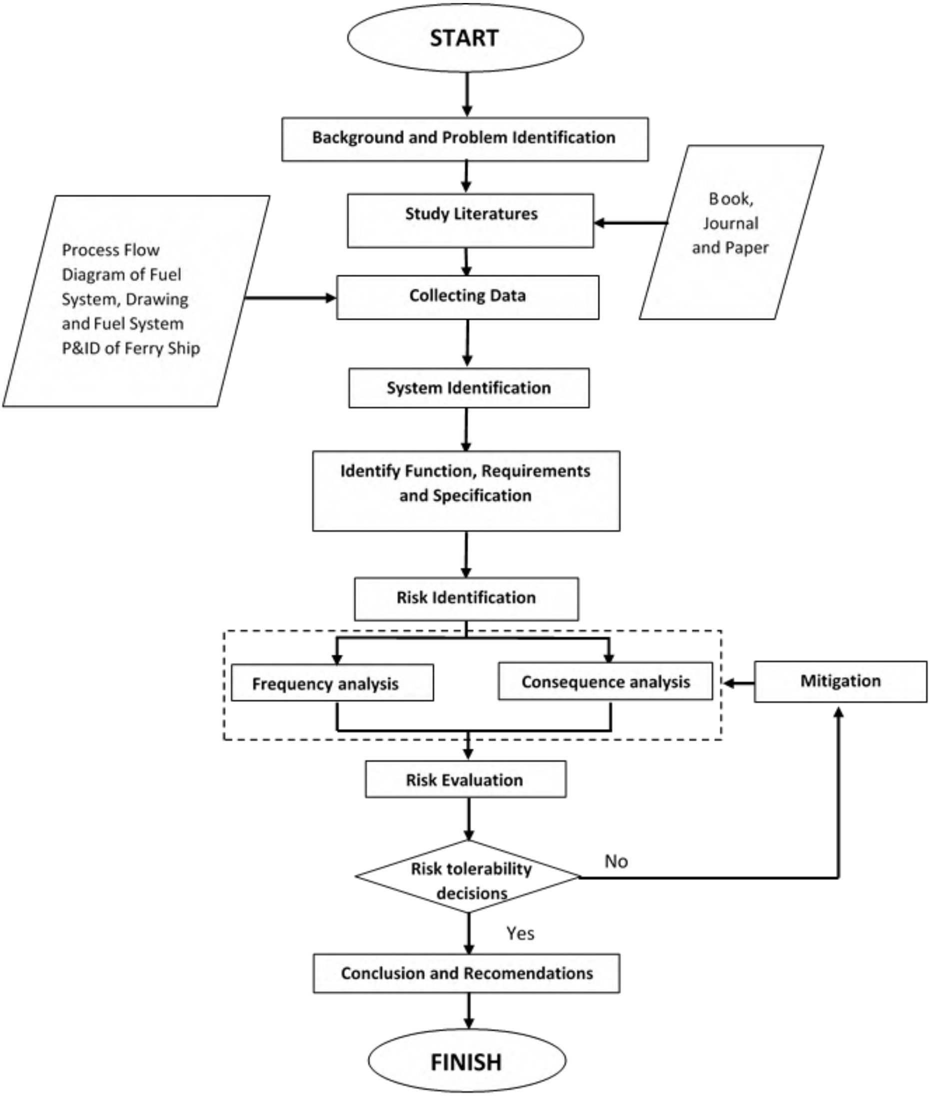
direct relationship that exists between the cause and resulting process failure mode.

6. **Frequency Analysis and Consequence Analysis**
   Analysis of the data in order to determine the levels of risk. By using FTA for frequency analysis and ALOHA for consequence analysis.

7. **Risk Evaluation.**
   This stage will be determined whether the risks are acceptable or not, the decisions are made based on Risk Matrix from MICOPERI Marine Contractors.

8. **Mitigation**
   If there are any intolerable risk after the risk evaluation, then will be do a mitigation act to minimize those risk by using LOPA method.

9. **Conclusions and Recommendations**
   Make conclusions based on the results obtained and suggestions for further research development.


START
Background and Problem Identification
Study Literatures
Book,
Journal
and Paper
Process Flow
Diagram of Fuel
System, Drawing
and Fuel System
P&ID of Ferry Ship
Collecting Data
System Identification
Identify Function, Requirements
and Specification
Risk Identification
Frequency analysis
Consequence analysis
Mitigation
Risk Evaluation
Risk tolerability
decisions
No
Yes
Conclusion and Recomendations
FINISH

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CHAPTER IV
DATA ANALYSIS AND FINDINGS

4.1. Data Analyze

On this chapter will be discussed further on about all data that required. Analyze data will be appropriated to the scope of problems which had determined.

4.1.1. Ships data

Viking Grace, Ro-Pax ferry, 2013

- 4 x Wärtsilä 8L50DF Engines
- Wärtsilä LNGPac
- 2 x Wärtsilä Built-up Propellers
- Wärtsilä Transverse Thrusters
- Wärtsilä Seals & Bearings

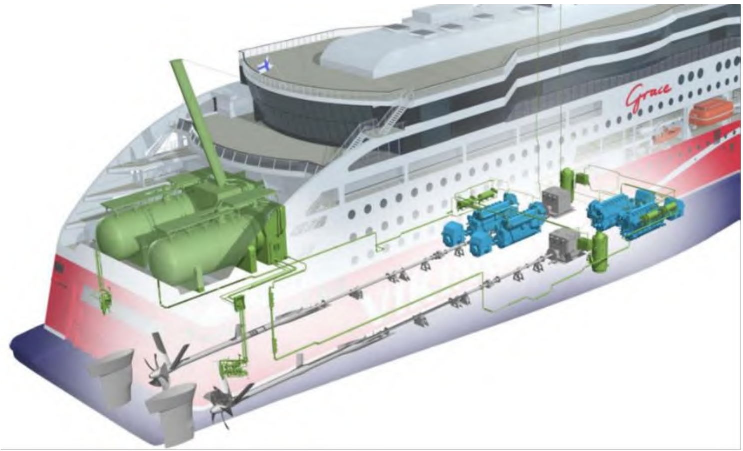


Figure 23 Viking Grace

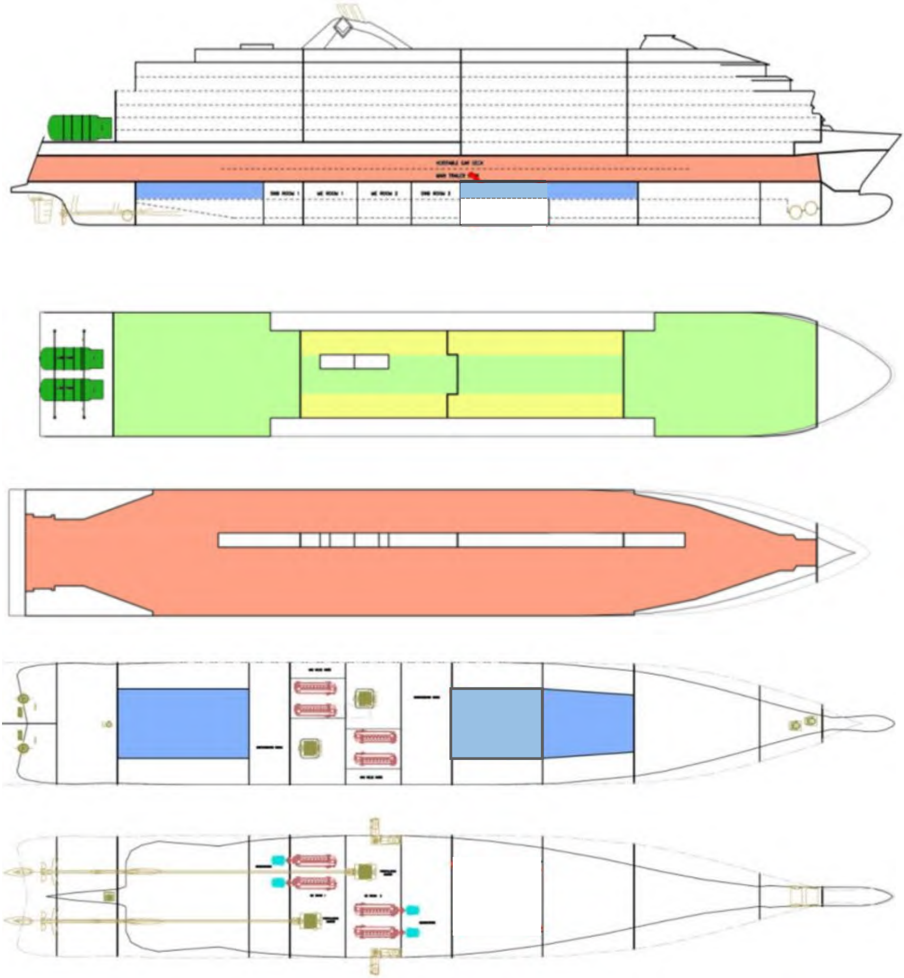


Figure 24 General Arrangement of Viking Grace

Table 5 *Ship's Data*

Name	**Viking Grace**
Type	Ro-Pax Cruise Ferry
Length Overall	218,21 m
Breadth Extreme	32,42 m
Gross Tonnage	57565 GT
Deadweight	6107 t
Service Speed	22 knots
Main Engine	4x8L50DF 7600 kW
Generator Set	4x6L50DF 5700kW
Route	Turku-Mariehamn-Stockholm
IMO	9606900
Owner	Viking Line Abp, Finland
Shipyard	STX Europe in Turku, Finland
Flag	Finland (FI)
Class	Lloyd's Register
Delivered	2013
Capacity	2800 passengers
Crew	200

Table 6 *LNGPac Data*

Type	LNGPac 200
Geometric volume (m^3)	200
Net volume (90%) (m^3)	180
Diameter (m)	4,3
Tank length (m)	19,1
Tank room (m)	2,7
Total length (m)	21,8
LNGPac empty weight (ton)	77
Tank full weight (ton)	163,4

Table 7 *Chemical properties*

Type	LNG
Physical state at 15^{o} C and 1 atm	Gas
Boiling point at 1 atm	-161^{o}C
Freezing point	-182,2^{o}C
Critical temperature	-82,2^{o}C
Critical pressure	45,78 atm
Specific gravity (liquid)	0,415-0,45 at -162^{o}C
Vapor (gas) specific gravity	0,55-1

The complete physical and chemical properties for liquefied natural gas has attached on Attachmnet I.

Table 8 *Ship's timetables*
Source: https://www.sales.vikingline.com/en/find-cruise-trip/timetable/turku-stockholm/

Turku		Mariehamn		Stockholm
08.45	>	14.10-14.25	>	18.55
19.50	<	14.10-14.25	<	07.45

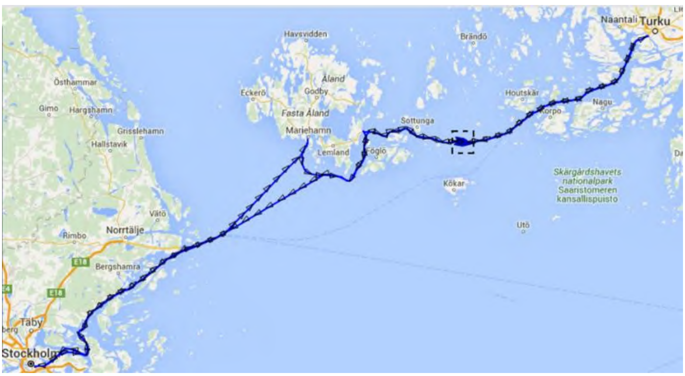


Figure 25 *Ship's Route*

Thu 13th Aug, 2015

Time	02:00	05:00	08:00	11:00	14:00	17:00	20:00	23:00
Weather								
Temp	17 °c	17 °c	17 °c	16 °c	16 °c	16 °c	13 °c	8 °c
Feels Like	16 °c	15 °c	17 °c	17 °c	18 °c	18 °c	13 °c	8 °c
Rain	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm
Wind	21 mph NNW	21 mph NNW	20 mph NNW	21 mph NNW	20 mph NNW	21 mph NNW	20 mph NNW	10 mph NNW
Gust	28 mph	29 mph	24 mph	23 mph	23 mph	23 mph	23 mph	16 mph
Rain?	0%	0%	0%	0%	0%	0%	0%	0%
Cloud	35%	9%	6%	1%	8%	26%	4%	3%
Humidity	85%	76%	77%	74%	70%	69%	69%	69%
Pressure	1019 mb	1020 mb	1021 mb	1023 mb	1023 mb	1023 mb	1023 mb	1024 mb

***Figure 26** Weather condition 13th Aug 2015 at Latitude 60,08 Longitude 21,09 (Ship's route Turku-Mariehamn)*

Source:http://www.worldweatheronline.com/v2/historical-weather.aspx?q=60.0812835408536,21.09375

The risk assessment on this Bachelor Thesis will be done to the weather condition of summer season (13th August 2015) with ship's route Turku-Mariehamn which located at Lat. 60,08 and Lon 21,09. This condition has be adapted with ship voyage schedule, could be seen on Figure 26 with red box.

4.1.2. P&ID of Fuel System

P&ID which will be used to analyze the problems will be appropriated to the scope of problems of this Thesis, there are:

- P&ID of Gas Storage and Supply System
- P&ID of Gas Valve Unit (GVU)
- P&ID of Internal fuel gas system

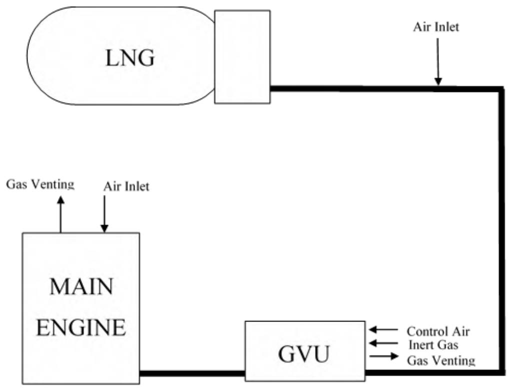
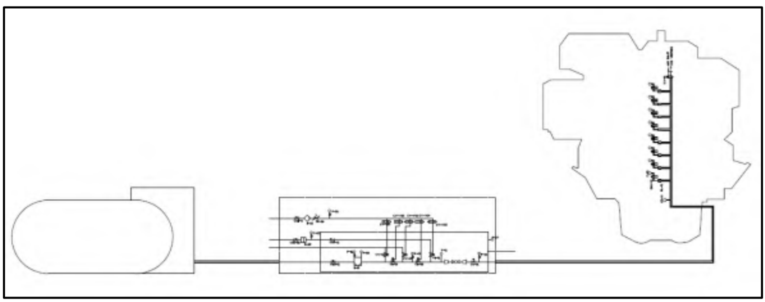


Figure 27 LNG Fuel System Arrangement



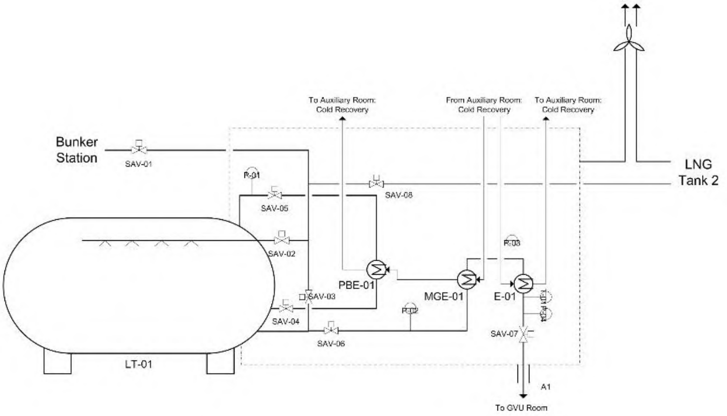


Figure 28 P&ID of Cool Box System (PBU-1)

Unit Components:

LT	: LNG Tank
SAV	: Solenoid Actuator Valve
PBE	: Pressure Build-Up Evaporator
MGE	: Main Gas Evaporator
E	: Evaporator

Sensors and Indicators:

P	: Pressure Transmitter
T	: Temperature Sensor

Pipe Connection:

A1	: Gas Outlet to GVU (5-10 bar)

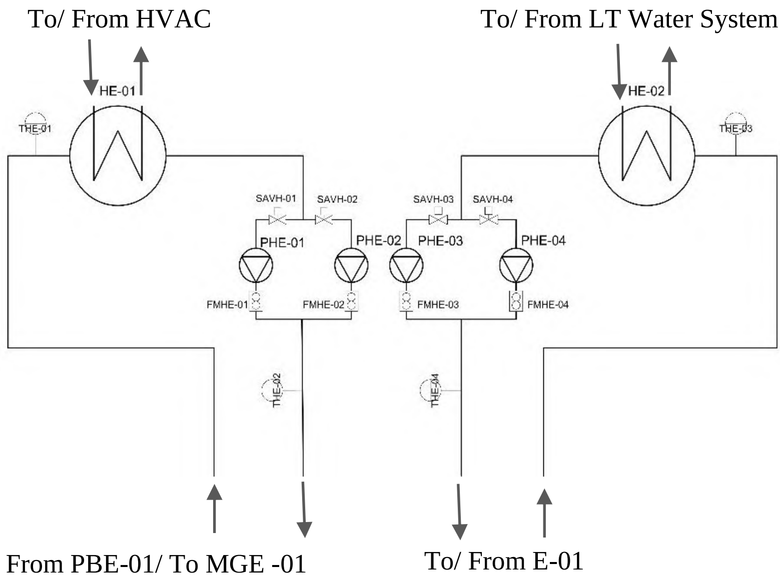


Figure 29 Auxiliary System (Heat Exchanger) (AXME-1)

Unit Components:

HE : Heat exchanger
SAV : Solenoid Actuator Valve
PHE : Centrifugal pump

Sensors and Indicators:

FMHE : Flow meter
THE : Temperature Sensor

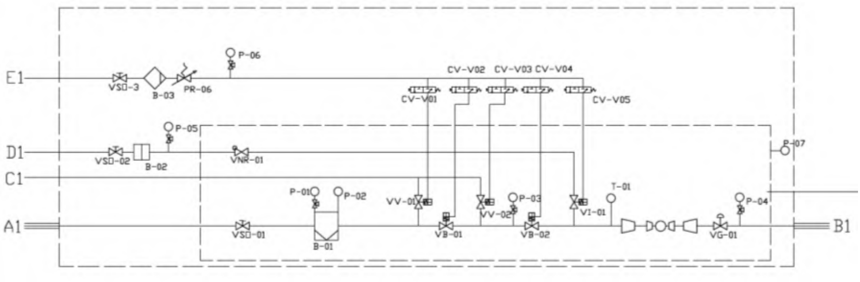


Figure 30 P&ID of Gas Valve Unit (GVU-1)

Unit Components:

VSO : Manual Shut off Valve
VNR : Non-Return Valve (Left to Right)
VV : Vent Valve
VB : Block Valve
VI : Inerting valve
VG : Gas Control Valve
PR : Pressure Regulator
B-01 : Gas Filter
B-02 : Inert Gas Filter
B0-3 : Control Air Filter
CV : Solenoid Valve

Sensors and Indicators:

P-01 : Pressure Transmitter Gas Inlet
P-02 : Pressure Transmitter Gas Inlet
P-03 : Pressure Transmitter
P-04 : Pressure Transmitter Gas Outlet
P-05 : Pressure Transmitter Inert Gas
P-06 : Pressure Transmitter Control Air
P-07 : Pressure Difference Transmitter
T : Temperature Sensor

Pipe Connection:

A1 : Gas Inlet (5-10 bar)
B1 : Gas Outlet to Main Engine
C1 : Gas Venting
D1 : Inert Gas (Max 15 bar)
E1 : Instrument Air (6-8 bar)

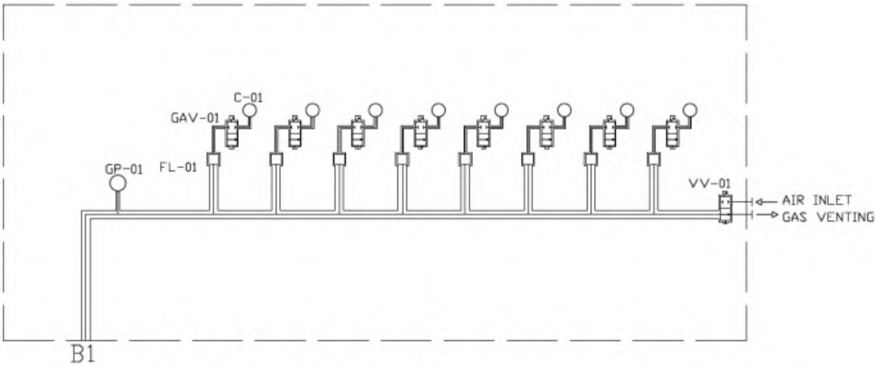


Figure 31 P&ID of Internal fuel gas system (FGS-1)

Unit Components:

FL : Gas Safety Filter
GAV : Gas Admission Valve
C : Cylinder
VV : Venting Valve

Sensors and Indicators:

GP : Gas Pressure Indicator

Pipe Connection:

B1 : Gas Inlet from Main Engine

4.1.3. Mode Operation

For mode operation on fuel system of dual fuel ship, there are three main mode, normal operation, tank pressure increase and bunkering procedure.

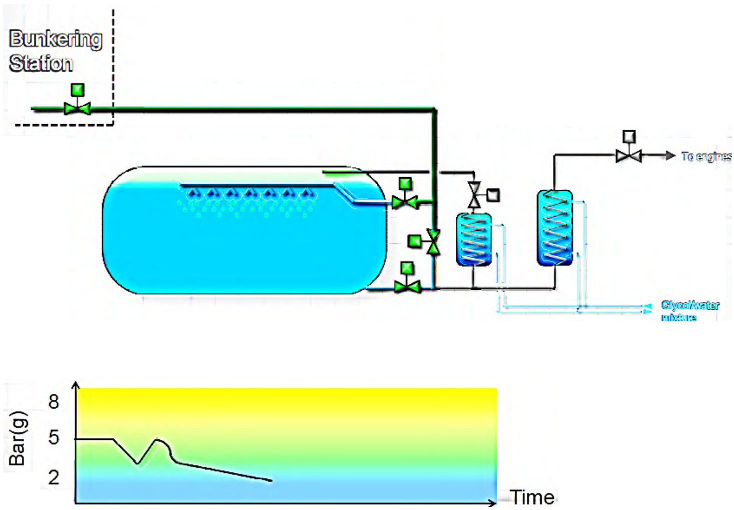


Figure 32 *Bunkering Procedure*
Source: Wärtsilä

Bunkering Procedure

1. Check that on board bunkering line is inerted and cooled down.
2. Collapse the gas pressure in the tank.
3. Open the main filling line.
4. Close the filling line valves.
5. Inert the piping with N_2.

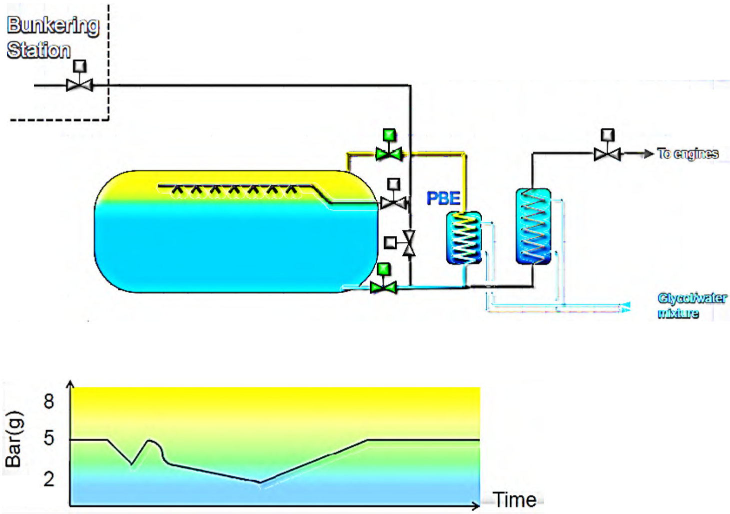


Figure 33 Tank Pressure Increase
Source: Wärtsilä

Tank Pressure Increase

1. Open pressure control valve.
2. LNG flow by the hydrostatic pressure into the vaporizer.
3. LNG is vaporized and gas is returned to the tank

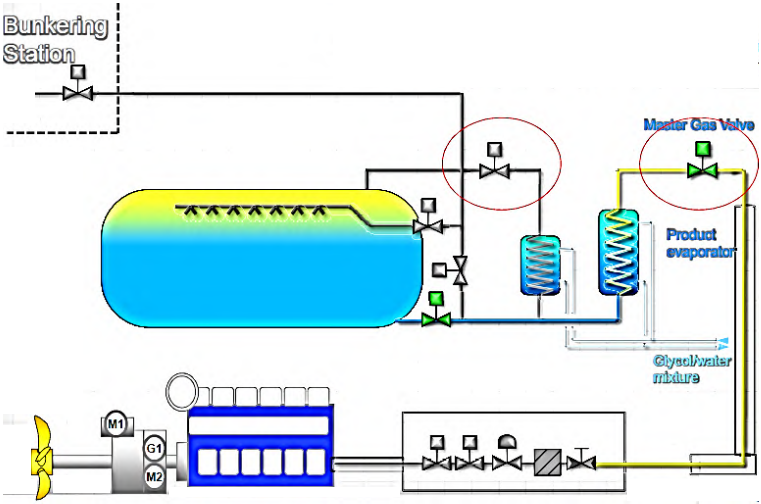


Figure 34 Normal Operation
Source: Wärtsilä

Normal Operation

1. The 'master gas valve' is opened (pneumatic actuated valve with manual override).
2. LNG is forced by tank pressure through the product evaporator and instantly evaporated.
3. Gas flows to the GVU.

4.2. Risk Assessment

There are three main step framework of risk assessment which must to fulfill, there are:

- Risk identification is the "process of finding, recognizing and describing risks", and involves "identification of risk sources, events, their causes and their potential consequences";

- Risk analysis is the “process to comprehend the nature of risk and to determine the level of risk”;
- Risk evaluation is the “process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable”.

On this sub-chapter will be discuss the risk assessment for the Process on Pressure Build up Evaporator (PBE) based on P&ID of Cool Box system. For the others risk assessment has attached on Attachment II.

4.2.1. Risk Identification

The first step on risk assessment which have to be done is risk identification. Risk identification on this Bachelor Thesis do by understanding function of all system which will be analyze. The result from risk identification is scenario of all failure modes. Example of failure modes list on HAZOP worksheet could be seen on the Table 9, the complete worksheet has attached on Attachment II.

For the example is the risk identification of Process on Pressure Build up Evaporator (PBE) which refer to P&ID of Cool Box System. The part of the system selected for examination is the line from the LNG tank with material as LNG liquid to the LNG tank as LNG vapor, this process has function to increase the pressure on the tank so the LNG liquid, which will being a vapor, will flow to the engine through the GVU system, as shown on Figure 35.

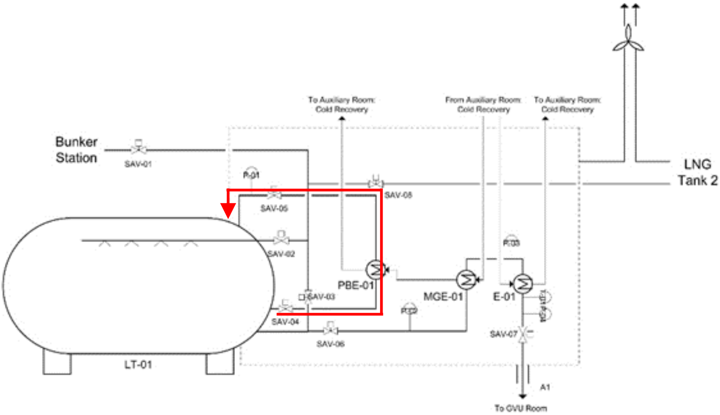


__Figure 35__ Example of risk identification on Process on Pressure Build up Evaporator (PBE)

The next step is identify the element or material which flow on the process and determine the design intent. Then decide the Guide Word and Element for obtaining Deviation, as shown on the figure below.

After obtaining Deviation, the next step is investigate cause, consequence and protection based on the system arrangement. For the consequence which has possibility of gas leakage or explosion will use ALOHA software.

Table 9 *HAZOP Worksheet*

STUDY TITLE: Process on Pressure Build up Evaporator (PBE)										SHEET: 1 of 2	
Drawing No.: PBU-1			REV. No.:							DATE: 25 April 2016	
PART CONSIDERED:			Transfer and evaporate LNG to increase tank pressure								
DESIGN INTENT: Min. 5			Material: LNG				Activity: Transfer and Evaporate				
Max. 20 (Pressure, bar)			Source: LNG Tank				Destination: LNG Tank				
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required
1	NO	LNG Transfer	No LNG transfer to tank	Failure on SAV-04 Valve, fail to open			Operation of dual fuel system will be delayed		Pressure transmitter P-01		
2	LESS	LNG Transfer	Less LNG transfer to tank	Leakage			Operation will be degraded because not enough pressure to transfering LNG to GVU and excessive pressure on cool box could generate explosion		Pressure transmitter P-01 and exchange fan		
3	MORE	LNG Transfer	More LNG transfer to tank	Failure on SAV-04 valve, fail to close			Excessive flow to the tank will increase tank pressure, if the pressure in tha tank more than 20 bar could inflict explosion		Pressure transmitter P-01		
4	NO	LNG Evaporate	Cannot evaporate LNG	Failure on evaporate system			Operation will be delayed because not enough pressure to transfering LNG to GVU		Flow meter on evaporator system		

4.2.2. Risk Analysis

After finished on risk identification step for all system, the next step is risk analysis to determine level of frequency and consequence which will be used as an input for the risk evaluation. For the example will be shown the risk analysis result from HAZOP of Process on Pressure Build up Evaporator (PBE).

Frequency value for each causes are decided from FTA method which had explained on sub-chapter 2.5.3. Frequency and Consequence Analysis (Page: 45-50). For value of Basic Event are obtained from OREDA 2002. After obtained the value of Failure Rates and Probability of Failure, the value will be matched to Table of Probability Description (Page: 44).

The FTA method will start from top event which refer to Possible Causes from HAZOP worksheet. For each causes will be given a code to simplify the process. For example, failure on SAV-04 Valve which cannot opened.

A1 PBU 1.1.

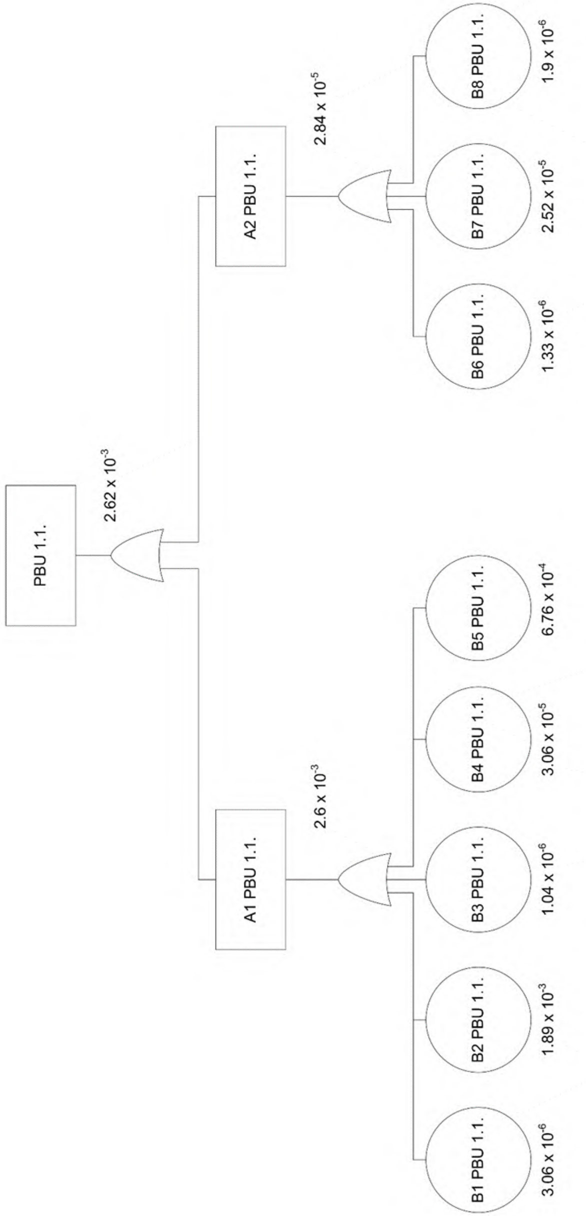
A : First level contributor (It will following alphabet for the next level)

1 : First contributors (It will following numerical order for the next causes)

PBU : System which have to identify from HAZOP Worksheet

1 : Failure mode’s number, based on HAZOP worksheet

1 : Potential cause order


PBU 1.1.
2.62 x 10^{-3}
A1 PBU 1.1.
2.6 x 10^{-3}
A2 PBU 1.1.
2.84 x 10^{-5}
B1 PBU 1.1.
3.06 x 10^{-6}
B2 PBU 1.1.
1.89 x 10^{-3}
B3 PBU 1.1.
1.04 x 10^{-6}
B4 PBU 1.1.
3.06 x 10^{-5}
B5 PBU 1.1.
6.76 x 10^{-4}
B6 PBU 1.1.
1.33 x 10^{-6}
B7 PBU 1.1.
2.52 x 10^{-5}
B8 PBU 1.1.
1.9 x 10^{-6}

Failure on SAV-04 valve (PBU 1.1.)

A1: Loss of power
A2: Fail to control valve
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Delay
B7: Fail to open
B8: Structural deficiency

The value of each event are decided based on gate type. Failure Probability for Basic Event will obtained from Failure Rates value, explained on sub-chapter 2.5.3 Frequency and Consequence Analysis (Page: 48-50). For example of PBU 1.1. First calculate the value of each basic event:

- B1 PBU 1.1.

  $P = 1- e^{-\lambda T}$

  P: Failure Probability
  λ: Failure Rate (OREDA 2002: 13.2 x10^{-6})
  T: Exposure Interval (OREDA 2002: 0.2323)

  $P_{B1} = 1- e^{-(13.2 \text{ x}10\text{^-}6) \text{ x}0.2323} = 3.06 \text{ x } 10^{-6}$

- B2 PBU 1.1.

  $P = 1- e^{-\lambda T}$

  P: Failure Probability
  λ: Failure Rate (OREDA 2002: 8140.51 x10^{-3})

T: Exposure Interval (OREDA 2002: 0.2323)

P_{B2} = 1- $e^{-(8140.51 \times 10^{\wedge}-6) \times 0.2323}$= 1.89 x 10^{-3}

- B3 PBU 1.1.

$P = 1- e^{-\lambda T}$

P: Failure Probability
λ: Failure Rate (OREDA 2002: 4.5 x10^{-6})
T: Exposure Interval (OREDA 2002: 0.2323)

P_{B3} = 1- $e^{-(4.5 \times 10^{\wedge}-6) \times 0.2323}$= 1.04 x 10^{-6}

- B4 PBU 1.1.

$P = 1- e^{-\lambda T}$

P: Failure Probability
λ: Failure Rate (OREDA 2002: 132.04 x10^{-6})
T: Exposure Interval (OREDA 2002: 0.2323)

P_{B4} = 1- $e^{-(132.04 \times 10^{\wedge}-6) \times 0.2323}$= 3.06 x 10^{-5}

- B5 PBU 1.1.

$P = 1- e^{-\lambda T}$

P: Failure Probability
λ: Failure Rate (OREDA 2002: 2911.25 x10^{-6})
T: Exposure Interval (OREDA 2002: 0.2323)

P_{B5} = 1- $e^{-(2911.25 \times 10^{\wedge}-6) \times 0.2323}$= 6.76 x 10^{-4}

- B6 PBU 1.1.

  $P = 1 - e^{-\lambda T}$

  P: Failure Probability
  λ: Failure Rate (OREDA 2002: 0.21 $x10^{-6}$)
  T: Exposure Interval (OREDA 2002: 6.3474)

  $P_{B6} = 1 - e^{-(0.21\ x10\wedge-6)\ x6.3474} = 1.33 \times 10^{-6}$

- B7 PBU 1.1.

  $P = 1 - e^{-\lambda T}$

  P: Failure Probability
  λ: Failure Rate (OREDA 2002: 3.98 $x10^{-6}$)
  T: Exposure Interval (OREDA 2002: 6.3474)

  $P_{B7} = 1 - e^{-(3.98\ x10\wedge-6)\ x6.3474} = 2.52 \times 10^{-5}$

- B8 PBU 1.1.

  $P = 1 - e^{-\lambda T}$

  P: Failure Probability
  λ: Failure Rate (OREDA 2002: 0.3 $x10^{-6}$)
  T: Exposure Interval (OREDA 2002: 6.3474)

  $P_{B1} = 1 - e^{-(0.3\ x10\wedge-6)\ x6.3474} = 1.9 \times 10^{-6}$

After finish with all basic event, then calculate the top event based on the gate.

Because there is an OR Gate then,

$P_{A1} = P_{B1} + P_{B2} + P_{B3} + P_{B4} + P_{B5} - P_{B1}P_{B2} - P_{B1}P_{B3} - P_{B1}P_{B4} - P_{B1}P_{B5} - P_{B2}P_{B3} - P_{B2}P_{B4} - P_{B2}P_{B5} - P_{B3}P_{B4} - P_{B3}P_{B5} - P_{B4}P_{B5} + P_{B1}P_{B2}P_{B3} + P_{B1}P_{B2}P_{B4} + P_{B1}P_{B2}P_{B5} + P_{B1}P_{B3}P_{B4} + P_{B1}P_{B3}P_{B35} + P_{B1}P_{B4}P_{B5} + P_{B2}P_{B3}P_{B4} + P_{B2}P_{B3}P_{B5} + P_{B2}P_{B4}P_{B5} + P_{B3}P_{B4}P_{B5} - P_{B1}P_{B2}P_{B3}P_{B4} - P_{B1}P_{B2}P_{B3}P_{B5} - P_{B1}P_{B2}P_{B4}P_{B5} - P_{B1}P_{B3}P_{B4}P_{B5} + P_{B1}P_{B2}P_{B3}P_{B4}P_{B5}$

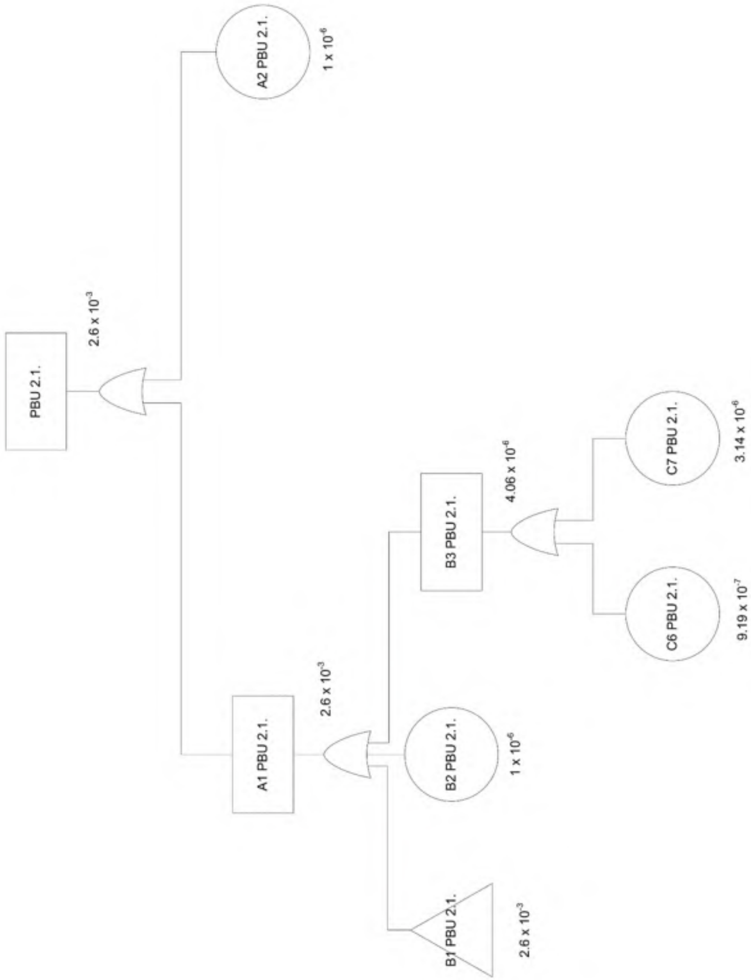
$P_{A1} = (3.06 \text{ x } 10^{-6}) + (1.89 \text{ x } 10^{-3}) + (1.04 \text{ x } 10^{-6}) + (3.06 \text{ x } 10^{-5}) + (6.76 \text{ x } 10^{-4}) - (3.06 \text{ x } 10^{-6})(1.89 \text{ x } 10^{-3}) - (3.06 \text{ x } 10^{-6})(1.04 \text{ x } 10^{-6}) - (3.06 \text{ x } 10^{-6})(3.06 \text{ x } 10^{-5}) - (3.06 \text{ x } 10^{-6})(6.76 \text{ x } 10^{-4}) - (1.89 \text{ x } 10^{-3})(1.04 \text{ x } 10^{-6}) - (1.89 \text{ x } 10^{-3})(3.06 \text{ x } 10^{-5}) - (1.89 \text{ x } 10^{-3})(6.76 \text{ x } 10^{-4}) - (1.04 \text{ x } 10^{-6})(3.06 \text{ x } 10^{-5}) - (1.04 \text{ x } 10^{-6})(6.76 \text{ x } 10^{-4}) - (3.06 \text{ x } 10^{-5})(6.76 \text{ x } 10^{-4}) + (3.06 \text{ x } 10^{-6})(1.89 \text{ x } 10^{-3})(1.04 \text{ x } 10^{-6}) + (3.06 \text{ x } 10^{-6})(1.89 \text{ x } 10^{-3})(3.06 \text{ x } 10^{-5}) + (3.06 \text{ x } 10^{-6})(1.89 \text{ x } 10^{-3})(6.76 \text{ x } 10^{-4}) + (3.06 \text{ x } 10^{-6})(1.04 \text{ x } 10^{-6})(3.06 \text{ x } 10^{-5}) + (3.06 \text{ x } 10^{-6})(1.04 \text{ x } 10^{-6})(6.76 \text{ x } 10^{-4}) + (3.06 \text{ x } 10^{-6})(3.06 \text{ x } 10^{-5})(6.76 \text{ x } 10^{-4}) + (1.89 \text{ x } 10^{-3})(1.04 \text{ x } 10^{-6})(3.06 \text{ x } 10^{-5}) + (1.89 \text{ x } 10^{-3})(1.04 \text{ x } 10^{-6})(6.76 \text{ x } 10^{-4}) + (1.89 \text{ x } 10^{-3})(3.06 \text{ x } 10^{-5})(6.76 \text{ x } 10^{-4}) + (1.04 \text{ x } 10^{-6})(3.06 \text{ x } 10^{-5})(6.76 \text{ x } 10^{-4}) - (3.06 \text{ x } 10^{-6})(1.89 \text{ x } 10^{-3})(1.04 \text{ x } 10^{-6})(3.06 \text{ x } 10^{-5}) - (3.06 \text{ x } 10^{-6})(1.89 \text{ x } 10^{-3})(1.04 \text{ x } 10^{-6})(6.76 \text{ x } 10^{-4}) - (3.06 \text{ x } 10^{-6})(1.89 \text{ x } 10^{-3})(3.06 \text{ x } 10^{-5})(6.76 \text{ x } 10^{-4}) - (3.06 \text{ x } 10^{-6})(1.04 \text{ x } 10^{-6})(3.06 \text{ x } 10^{-5})(6.76 \text{ x } 10^{-4}) + (3.06 \text{ x } 10^{-6})(1.89 \text{ x } 10^{-3})(1.04 \text{ x } 10^{-6})(3.06 \text{ x } 10^{-5})(6.76 \text{ x } 10^{-4}) = \mathbf{2.6 \text{ x } 10^{-3}}$

$P_{A2} = P_{B6} + P_{B7} + P_{B8} - P_{B6}P_{B7} - P_{B6}P_{B8} - P_{B7}P_{B8} + P_{B6}P_{B7}P_{B8}$

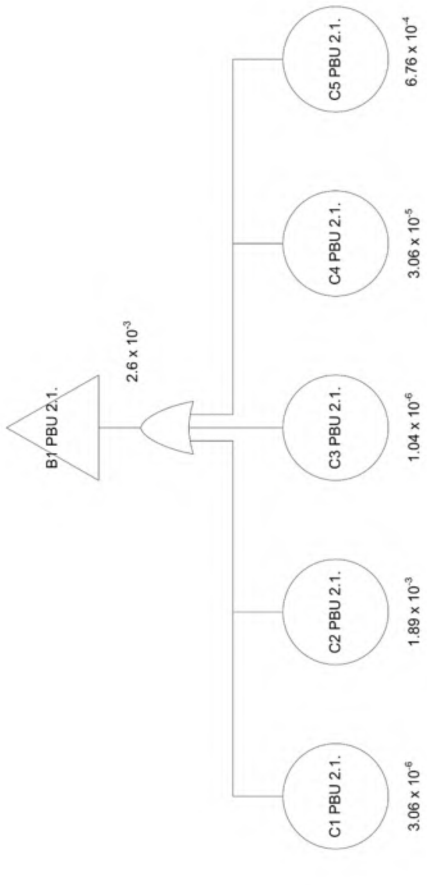
$P_{A2} = (1.33 \text{ x } 10^{-6}) + (2.52 \text{ x } 10^{-5}) + (1.9 \text{ x } 10^{-6}) - (1.33 \text{ x } 10^{-6})(2.52 \text{ x } 10^{-5}) - (1.33 \text{ x } 10^{-6})(1.9 \text{ x } 10^{-6}) - (2.52 \text{ x } 10^{-5})(1.9 \text{ x } 10^{-6}) + (1.33 \text{ x } 10^{-6})(2.52 \text{ x } 10^{-5})(1.9 \text{ x } 10^{-6}) = \mathbf{2.84 \text{ x } 10^{-5}}$

$P_{F\,(PBU1.1.)} = P_{A1} + P_{A2} - P_{A1}P_{A2}$

$P_{F\,(PBU1.1.)} = (2.6 \text{ x } 10^{-3}) + (2.84 \text{ x } 10^{-5}) - (2.6 \text{ x } 10^{-3})(2.84 \text{ x } 10^{-5}) = \mathbf{2.62 \text{ x } 10^{-3}}$

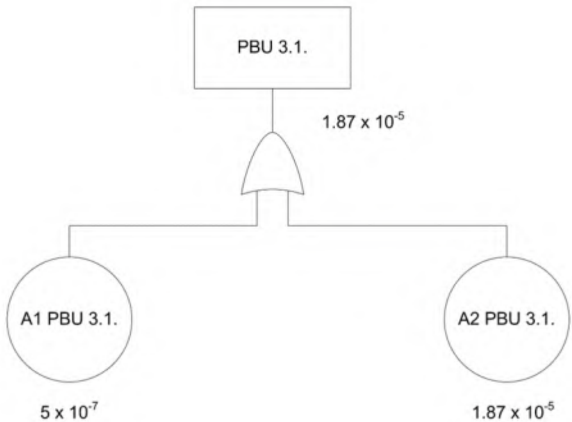


PBU 2.1.
2.6 x 10^-3
A2 PBU 2.1.
1 x 10^-6
A1 PBU 2.1.
2.6 x 10^-3
B3 PBU 2.1.
4.06 x 10^-6
C7 PBU 2.1.
3.14 x 10^-6
C6 PBU 2.1.
9.19 x 10^-7
B2 PBU 2.1.
1 x 10^-6
B1 PBU 2.1.
2.6 x 10^-3

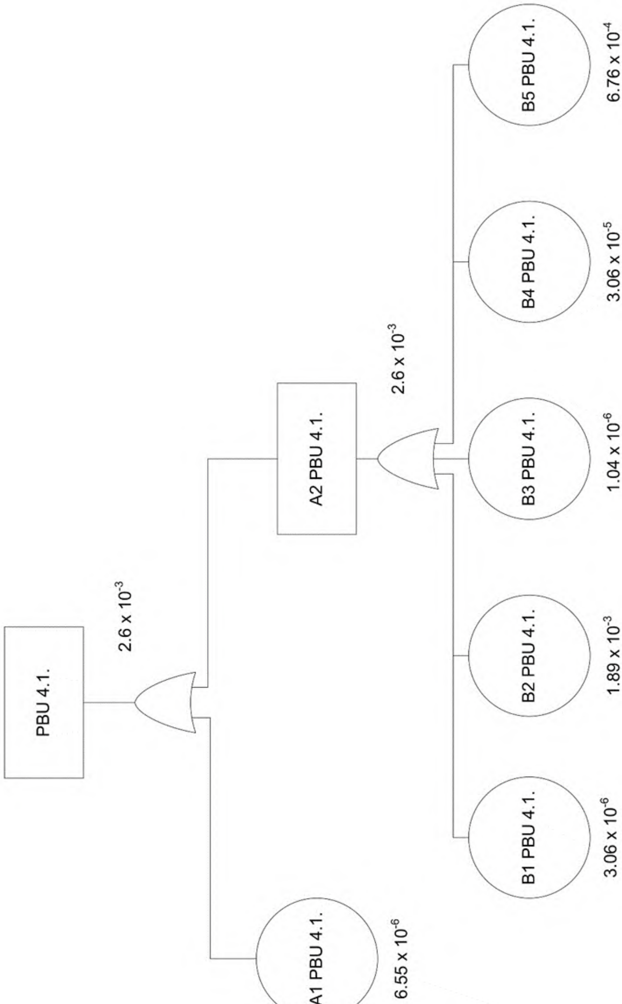

B1 PBU 2.1.
2.6 x 10-3
C1 PBU 2.1.
3.06 x 10-6
C2 PBU 2.1.
1.89 x 10-3
C3 PBU 2.1.
1.04 x 10-6
C4 PBU 2.1.
3.06 x 10-5
C5 PBU 2.1.
6.76 x 10-4

Failure on evaporate system (PBU 2.1.)

A1: Failure on pump
A2: Fail to regulate valve
B1: Loss of power
B2: Fail to start electric motor pump
B3: Pump is broken
C1: Breakdown
C2: Fail to start on demand
C3: Fail to synchronize
C4: Low output
C5: Spurious stop
C6: Fail to start pump
C7: Noise

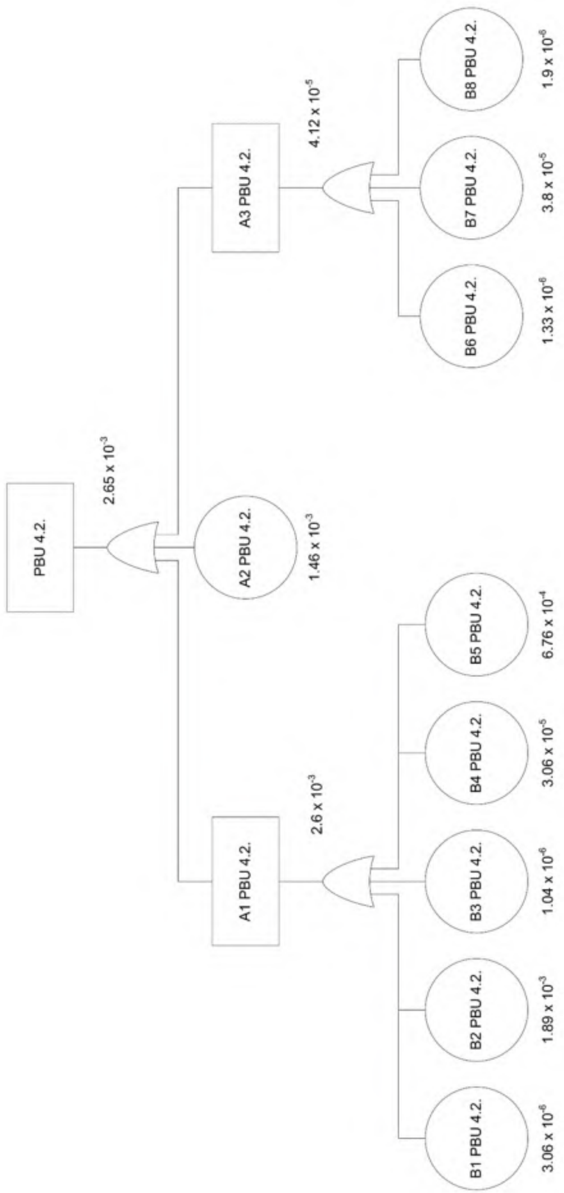


Leakage (PBU 3.1.)
A1: Pipe being rupture
A2: External leakage on valve


PBU 4.1.
2.6 x 10^{-3}
A1 PBU 4.1.
6.55 x 10^{-6}
A2 PBU 4.1.
2.6 x 10^{-3}
B1 PBU 4.1.
3.06 x 10^{-6}
B2 PBU 4.1.
1.89 x 10^{-3}
B3 PBU 4.1.
1.04 x 10^{-6}
B4 PBU 4.1.
3.06 x 10^{-5}
B5 PBU 4.1.
6.76 x 10^{-4}

Fail to monitor pressure on the tank (PBU 4.1.)

A1: Failure on pressure sensor
A2: Loss of power
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop


PBU 4.2.
2.65 x 10^{-3}
A1 PBU 4.2.
2.6 x 10^{-3}
A2 PBU 4.2.
1.46 x 10^{-3}
A3 PBU 4.2.
4.12 x 10^{-5}
B1 PBU 4.2.
3.06 x 10^{-6}
B2 PBU 4.2.
1.89 x 10^{-3}
B3 PBU 4.2.
1.04 x 10^{-6}
B4 PBU 4.2.
3.06 x 10^{-5}
B5 PBU 4.2.
6.76 x 10^{-4}
B6 PBU 4.2.
1.33 x 10^{-6}
B7 PBU 4.2.
3.8 x 10^{-5}
B8 PBU 4.2.
1.9 x 10^{-6}

Fail to close SAV-05 valve (PBU 4.2.)

A1: Loss of power
A2: Internal leakage on valve
A3: Fail to control valve
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Delay
B7: Fail to close
B8: Structural deficiency

After obtaining all the value of frequency the next step is determine the level of consequence, to determine it will be used table of Severity Description (Page 44). While for the consequence which generate an explosion or gas leakage will be used ALOHA software.

ALOHA has function to knowing the area of an explosion or gas leakage based on chemical properties and environment condition. ALOHA result will be plotted to general arrangement drawing to knowing if there are any victim on that area or not. The complete result from ALOHA has attached on Attachment II.

Because on HAZOP worksheet of Process on Pressure Build up Evaporator (PBE) there are consequence which has possibility to generate an explosion then ALOHA software will be used for consequence analysis. For the others consequence will be matched with the description from table of Severity Description.

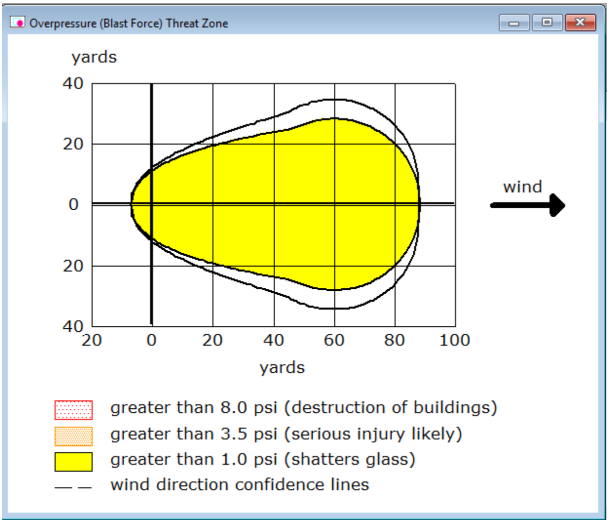


__Figure 36__ Example of ALOHA (Threat Zone)

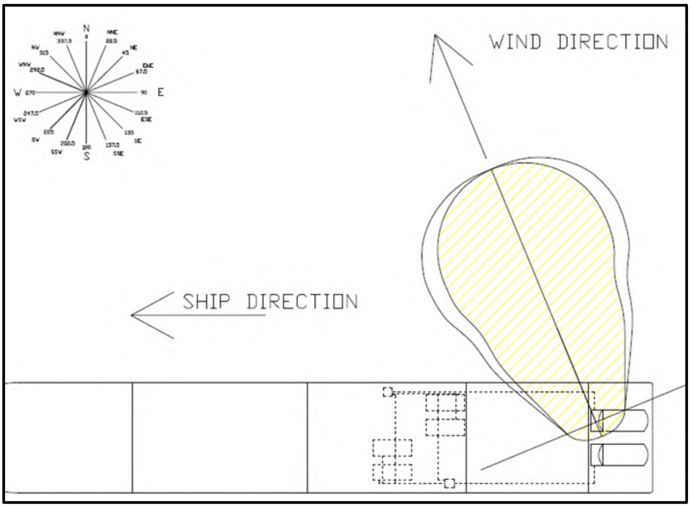


__Figure 37__ Result of ALOHA (Threat Zone) on Ship's General Arrangement

4.2.3. Risk Evaluation

For the risk evaluation will be give an example from failure mode Failure on SAV-04 Valve which cannot opened. Based on risk analysis, table of severity and table of probability these failure has a level of severity on 4 and level of probability on 3. Those result will be plotted on risk matrix from MICOPERI Marine Contractors.

STUDY TITLE: Process on Pressure Build up Evaporator (PBE)							
Drawing No.: PBU-1			REV. No.:				
PART CONSIDERED:			Transfer and evaporate LNG to increase tank pressure				
DESIGN INTENT: Min. 5			Material: LNG				Activity: Transfer and E
Max. 20 (Pressure, bar)			Source: LNG Tank				Destination: LNG Tank
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences
1	NO	LNG Transfer	No LNG transfer to tank	Failure on SAV-04 Valve, fail to open			Operation of dual fuel system will be delayed
2	LESS	LNG Transfer	Less LNG transfer to tank	Leakage			Operation will be degraded because not enough pressure to transfering LNG to GVU and excessive pressure on cool box could generate explosion

Figure 38 *Consequence from Failure on SAV-04 Valve*

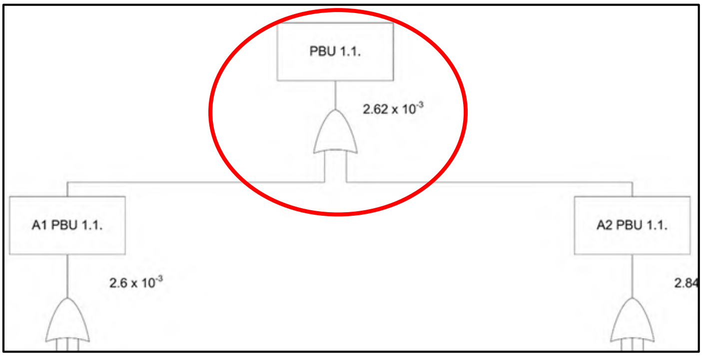


Figure 39 *Frequency from Failure on SAV-04 Valve*

Table 10 Severity Description from Failure on SAV-04 Valve

Rank	Description
1	Minor: Minor injury/ no internal disruption.
2	Moderate: Injury which requires medical attention/ minor internal disruption.
3	Significant: Potentially life threatening injury causing temporary disability and/or requiring medevac/ disruption which may cause performance degraded, possibly requiring corrective action.
4	Serious: Major life threatening injury or causing permanent disability/ incomplete recovery/ pollution with significant impact/ very serious disruption which may cause delayed on operational.
5	Catastrophic: Fatality or multiple fatalities or multiple life threatening injuries causing permanent disabilities/ total loss.

Table 11 Probability Description from Failure on SAV-04 Valve

Rank	Description	Probability
1	Very Unlikely: Could only occur under a freak combination of factors.	$< 10^{-5}$
2	Unlikely: May occur only in exceptional circumstances.	$10^{-5} – 10^{-4}$
3	Possible: Could occur at some time.	$10^{-4} – 10^{-2}$
4	Likely: Would not require extraordinary factors to occur at some time.	$10^{-2} – 10^{-1}$
5	Frequent: Almost certain to happen if conditions remain unchanged.	$10^{-1} – 1$

MICOPERI Risk Matrix			PROBABILITY				
			1	2	3	4	5
			Very Unlikely	Unlikely	Possible	Likely	Frequent
SEVERITY	1	Minor	1	2	3	4	5
	2	Moderate	2	4	6	8	10
	3	Significant	3	6	9	12	15
	4	Serious	4	8	12	16	20
	5	Catastrophic	5	10	15	20	25

Where:

1-2 : Low risk area, the potential hazards are under control.

3-8 : Moderate risk area, there is the need to verify that the potential hazards are under control and improve the measures already adopted.

9-15 : Medium risk area, there is the need to identify and schedule protection and prevention measures to be adopted in order to reduce or the probability P or the potential damage S.

16-25 : High risk area, there is the need to identify and schedule protection and prevention measures to be adopted in order to reduce the probability of the potential hazard (they shall be considered as urgent).

The result from risk matrix shown that the Failure on SAV-04 Valve which cannot opened has a level of risk on point 12. That is mean these failure shall be reduced. To reduce the risk level from these failure the mitigation will be applied, the mitigation will use LOPA method.

Worksheet on the below shown the risk evaluation for Process on Pressure Build up Evaporator (PBE), for the others evaluation has attached on Attachment II.

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Table 12 *Result on HAZOP Worksheet*

STUDY TITLE: Process on Pressure Build up Evaporator (PBE)										SHEET: 1 of 2	
Drawing No.: PBU-1			REV. No.:							DATE: 25 April 2016	
PART CONSIDERED:			Transfer and evaporate LNG to increase tank pressure								
DESIGN INTENT: Min. 5 Max. 20 (Pressure, bar)			Material: LNG				Activity: Transfer and Evaporate				
			Source: LNG Tank				Destination: LNG Tank				
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required
1	NO	LNG Transfer	No LNG transfer to tank	Failure on SAV-04 Valve, fail to open	2.62×10^{-3}	3	Operation of dual fuel system will be delayed	4	Pressure transmitter P-01	12	Yes
2	LESS	LNG Transfer	Less LNG transfer to tank	Leakage	9.27×10^{-5}	2	Operation will be degraded because not enough pressure to transfering LNG to GVU and excessive pressure on cool box could generate explosion	5	Pressure transmitter P-01 and exchange fan	10	No
3	MORE	LNG Transfer	More LNG transfer to tank	Failure on SAV-04 valve, fail to close	2.63×10^{-3}	3	Excessive flow to the tank will increase tank pressure, if the pressure in tha tank more than 20 bar could inflict explosion	5	Pressure transmitter P-01	15	Yes
4	NO	LNG Evaporate	Cannot evaporate LNG	Failure on evaporate system	2.6×10^{-3}	3	Operation will be delayed because not enough pressure to transfering LNG to GVU	4	Flow meter on evaporator system	12	Yes

STUDY TITLE: Process on Pressure Build up Evaporator (PBE)											SHEET: 2 of 2	
Drawing No.: PBU-1			REV. No.:								DATE: 25 April 2016	
PART CONSIDERED:			Transfer and evaporate LNG to increase tank pressure									
DESIGN INTENT: Min. 5			Material: LNG				Activity: Transfer and Evaporate					
Max. 20 (Pressure, bar)			Source: LNG Tank				Destination: LNG Tank					
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required	
5	LESS	LNG Vapor	Less LNG vapor which will be transferred to the tank	Leakage	9.27×10^{-5}	2	Operation will be degraded because not enough pressure to transfering LNG to GVU and excessive pressure on cool box could generate explosion	5	Pressure transmitter P-01 and exchange fan	10	No	
6	MORE	LNG Vapor	More LNG vapor which will be transferred to the tank	Fail to monitor pressure on the tank	2.6×10^{-3}	3	Excessive pressure on the tank and very potential to be an explosion	5	Pressure transmitter P-01	15	Yes	
				Failure on SAV-05 valve, fail to close	2.65×10^{-3}	3	Excessive pressure on the tank and very potential to be an explosion	5	Pressure transmitter P-01	15	Yes	

4.3. Mitigation

The result of Risk Evaluation, can be seen on HAZOP Worksheet, shown that some failure mode scenarios are on the Moderate rang High Risk level, there for needed action to reduce the risk level. Mitigation act is need to be done on those scenario where the risk need to identify and schedule protection and prevention measures to be adopted in order to reduce the frequency.

Mitigation act on this Bachelor Thesis use LOPA Method. First step of LOPA method is re-write all failure scenario form HAZOP Worksheet, such as Consequence description, Consequence category, Risk tolerance criteria and Initiating event.

The next step is adding all items that should be installed, those items are need to be installed to reduce the frequency of risk or could be used as early detection on failure case. Items which is installed on the system can be called IPL or Independent Protection Layer, for each IPL has a PFD (Potential Failure on Demand) value, these value can be obtained from OREDA database, OGP, etc.

For the example of mitigation using LOPA method which refer from HAZOP Worksheet could be seen on the Table 13, below, failure mode “No LNG transfer to tank caused by failure on SAV-04 Valve, fail to open”.

Table 13 LOPA Worksheet No LNG transfer to tank caused by failure on SAV-04 Valve, fail to open

Scenario No. 1	No LNG transfer to tank caused by failure on SAV-04 Valve, fail to open		Node No. 1
Date: 20 June 2016	Description	Probability	Frequency (per year)
Consequence description/ Category	Operation of dual fuel system will be delayed/ 4		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on SAV-04 Valve, fail to open		2.62×10^{-3}
Frequency of Unmitigated Consequence			2.62×10^{-3}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	Low pressure alarm	5.01×10^{-3}	
Total PFD		3.28×10^{-8}	
Frequency of Mitigated Consequence			8.59×10^{-11}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. Low pressure alarm should be installed		

From the worksheet (Table 13) shown that frequency of mitigated consequence for failure mode No LNG transfer to tank caused by failure on SAV-04 Valve, fail to open has been reduce to 8.59×10^{-11}, these result obtained from multiple of Frequency of unmitigated consequence with total PFD value of Independent Protection Layers. After that the final value of Frequency of mitigated consequence need to re-evaluation on risk matrix if the result on risk matrix shown on low risk level than the risk has been mitigate successfully. The result of risk matrix for failure mode No LNG transfer to tank caused by failure on SAV-04 Valve, fail to open shown on the figure below (Figure 40-41).

MICOPERI Risk Matrix			PROBABILITY				
			1	2	3	4	5
			Very Unlikely	Unlikely	Possible	Likely	Frequent
SEVERITY	1	Minor	1	2	3	4	5
	2	Moderate	2	4	6	8	10
	3	Significant	3	6	9	12	15
	4	Serious	4	8	12	16	20
	5	Catastrophic	5	10	15	20	25

Figure 40 *Unmitigated Risk Matrix*

MICOPERI Risk Matrix			PROBABILITY				
			1	2	3	4	5
			Very Unlikely	Unlikely	Possible	Likely	Frequent
SEVERITY	1	Minor	1	2	3	4	5
	2	Moderate	2	4	6	8	10
	3	Significant	3	6	9	12	15
	4	Serious	4	8	12	16	20
	5	Catastrophic	5	10	15	20	25

Figure 41 *Mitigated Risk Matrix*

From the figure showing that risk level has been successfully mitigated because the risk level has reduce to low risk. For the other scenario has attached on Attachment II.

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ATTACHMENT I

1. Pipe Dimension
2. LNG Specification
3. Viking Grace General Arrangement

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PIPE DIMENSION

Pipe	Material	Size	Pressure Class
A1 Pipe	Stainless Steel	DN100/150	PN16
B1 Pipe	Stainless Steel	DN100/150	PN16
Pipe on Cool Box	Stainless Steel	DN100	PN40
Pipe on GVU	Stainless Steel	DN100	PN40
Gas system ventilation	Stainless Steel	DN50	PN40
C1 Pipe	Stainless Steel	DN32	PN16
D1 Pipe	Stainless Steel	G1”	PN16
E1 Pipe	Stainless Steel	G1/2”	PN10

LIQEFIED NATURAL GAS

CAUTIONARY RESPONSE INFORMATION

FIRE

Flammable

- Flashback along vapor trail may occur.
- May explode if ignited in an enclosed area.
- Stop discharge if possible
- Cool exposed area and men effecting shutoff with water.

EXPOSURE

Vapor

- Not irritating to eyes, nose or throat.
- If inhaled, will cause dizziness, difficult breathing or loss of consciousness.
- If breathing is difficult, give oxygen.
- If breathing has stopped, give artificial respiration.

Liquid

- Will cause frostbite.
- Flush affected areas with plenty of water.

WATER POLLUTION

- No harmful to aquatic life.

HEALTH HAZARDS

Personal protective equipment :
Self-contained breathing apparatus; protective clothing if exposed to liquid.

Symptoms following exposure :
If concentration of gas is high enough, may cause asphyxiation. No detectable systematic effects, even at 5% concentration in air.

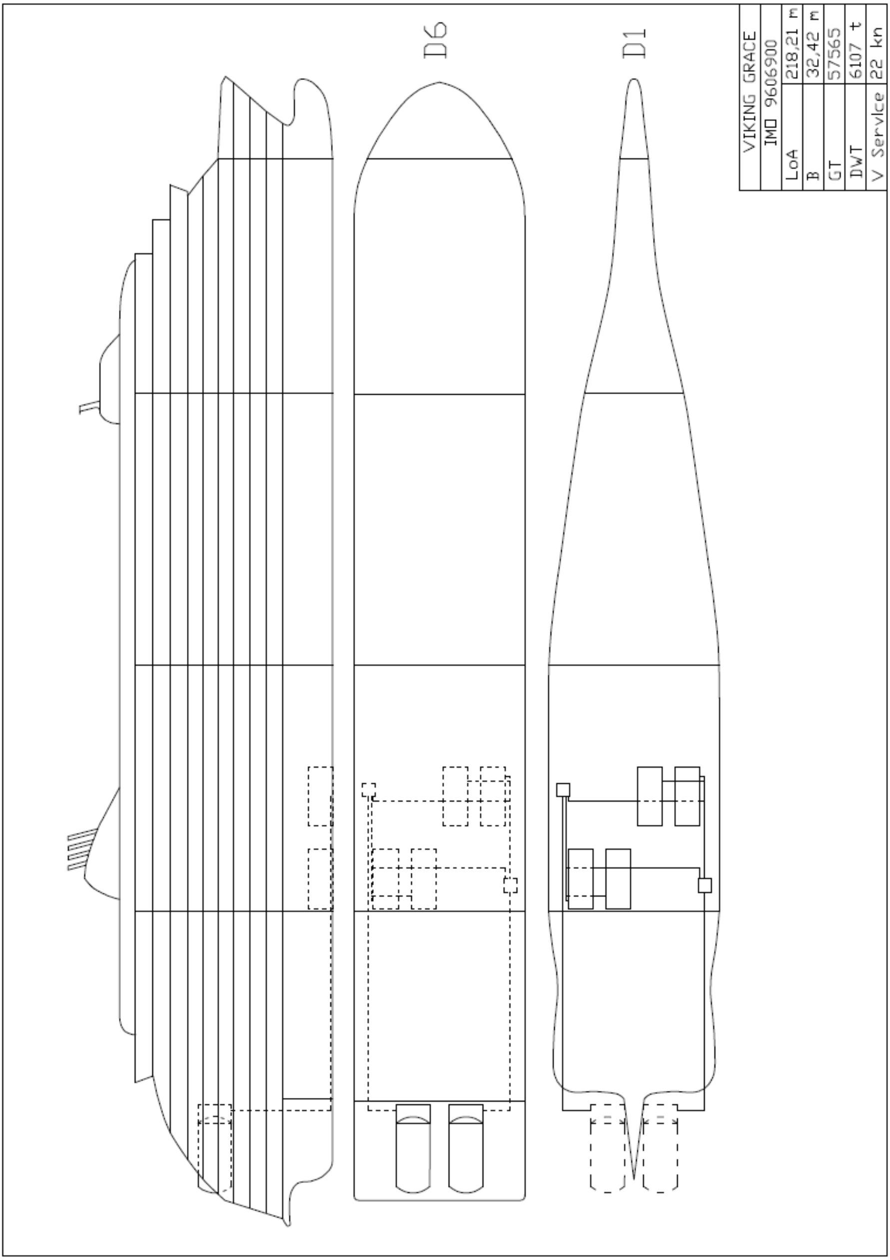
Treatment of exposure :
Remove victim to open air. If he/she is overcome by gas, apply artificial resuscitation.

Vapor irritant characteristic :
Vapors are nonirritating to the eyes and throat.

Liquid characteristic :
No appreciable hazard. Practically harmless to the skin because it is very volatile and evaporates quickly. May cause some frostbite.

PHYSICAL AND CHEMICAL PROPERTIES

Physical state at 15^{o}C; 1 atm	Gas
Molecular weight	>16
Boiling point at 1 atm	-161^{o}C
Freezing point	-182,2^{o}C
Critical temperature	-82,2^{o}C
Critical pressure	45,78 atm
Specific gravity	0,415-0,45 at -162^{o}C
Liquid surface tension	0,014 N/m at -161^{o}C
Vapor specific gravity	0,55-1
Ratio of specific heats of vapor	1,306
Latent heat of vaporization	5,1x10^{5} J/kg
Heat of combustion	-502,4 to -544,3 x 10^{5} J/kg


D6
D1
VIKING GRACE
IMO 9606900
LoA 218,21 m
B 32,42 m
GT 57565
DWT 6107 t
V Service 22 kn

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ATTACHMENT II

1. Frequency analysis using FTA
2. Consequence analysis using ALOHA
3. HAZOP Analysis and risk evaluation result
4. Mitigation

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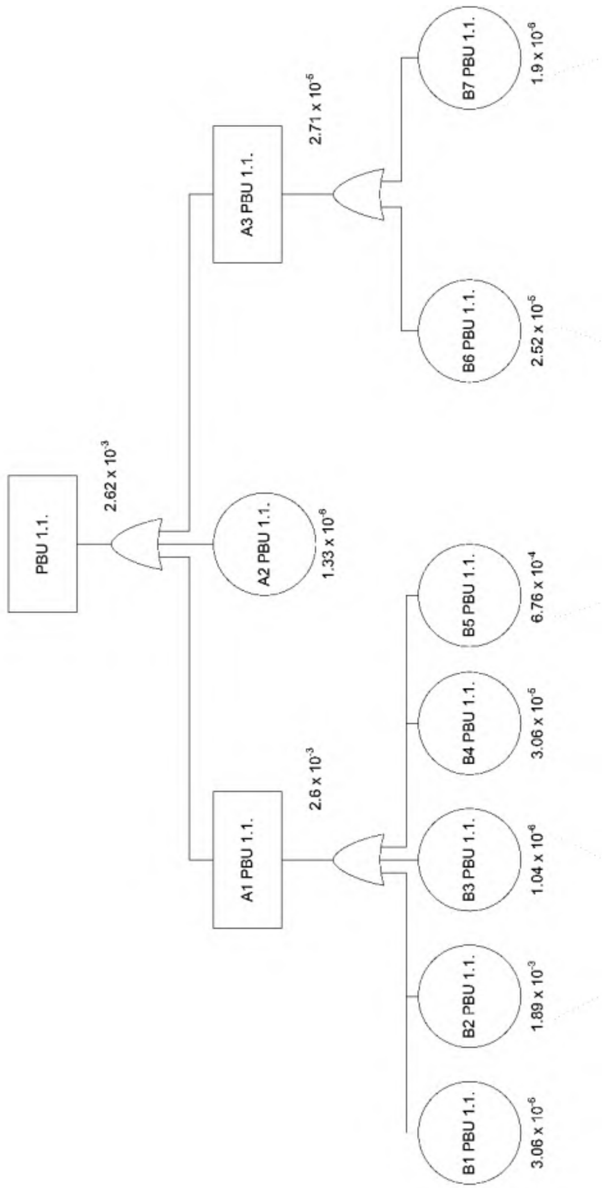
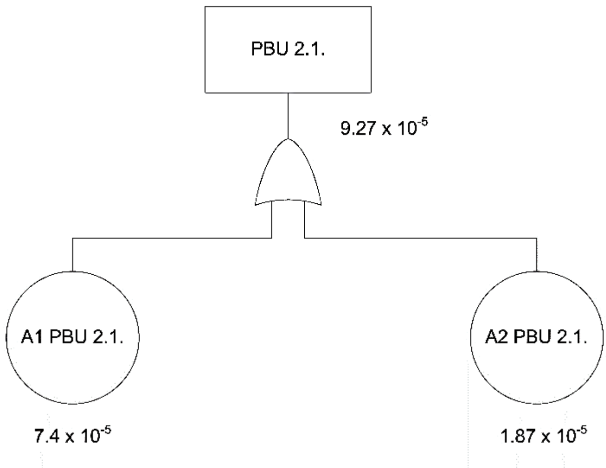
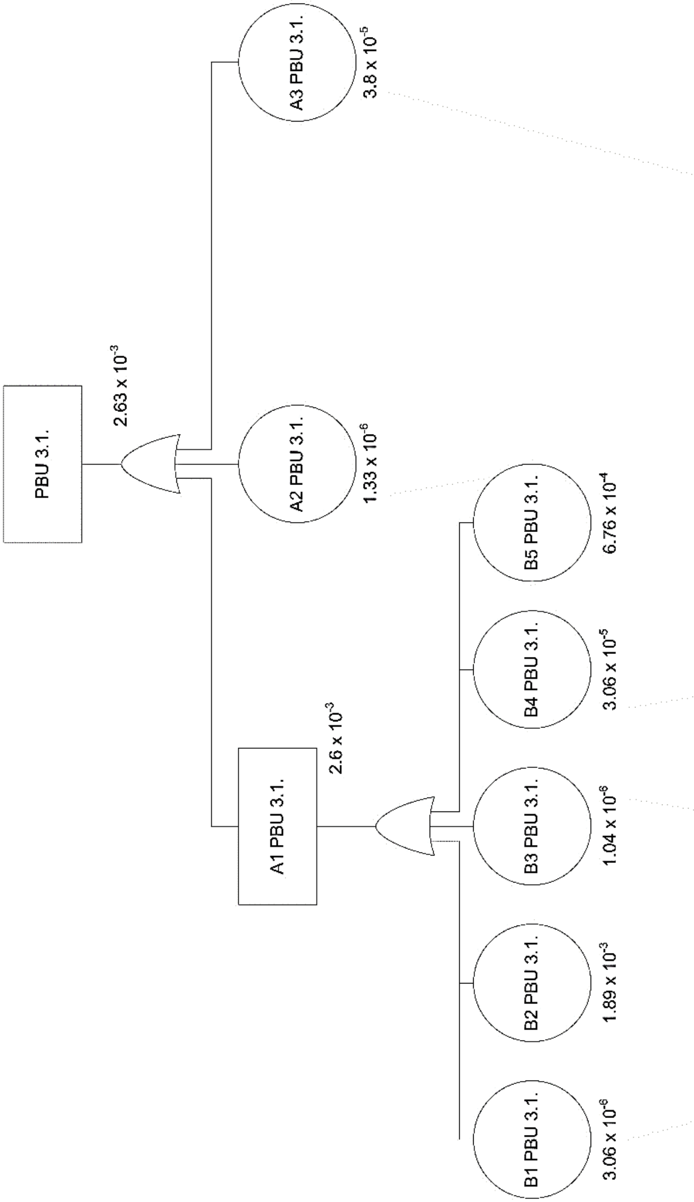
FREQUENCY ANALYSIS USING FTA



Failure on SAV-04 valve, fail to open (PBU 1.1.)
A1: Loss of power
A2: Delay
A3: Fail to control valve
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Fail to open
B7: Structural deficiency

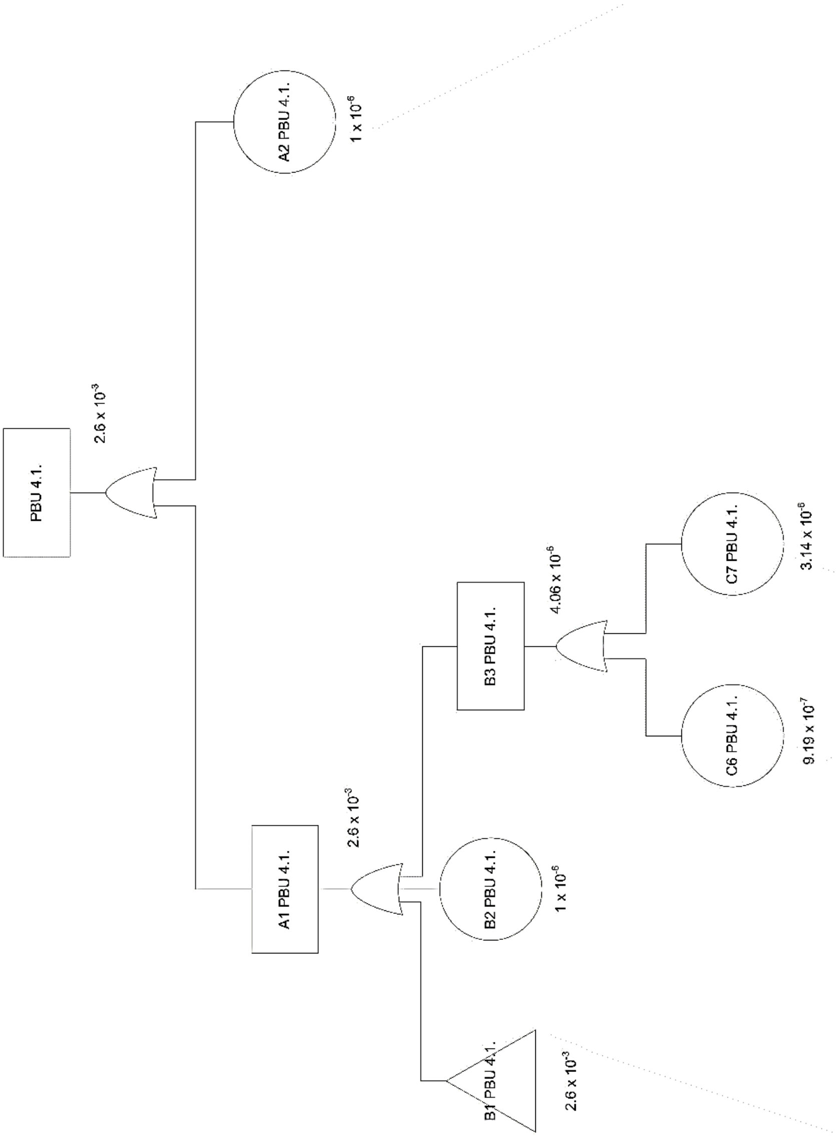


Leakage (PBU 2.1.)
A1: Pipe being rupture
A2: External leakage on valve

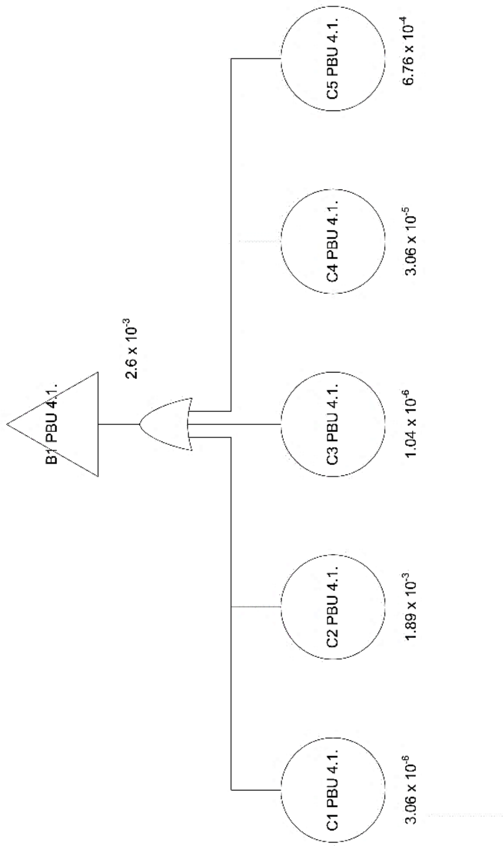

PBU 3.1.
2.63×10^{-3}
A1 PBU 3.1.
2.6×10^{-3}
A2 PBU 3.1.
1.33×10^{-6}
A3 PBU 3.1.
3.8×10^{-5}
B1 PBU 3.1.
3.06×10^{-6}
B2 PBU 3.1.
1.89×10^{-3}
B3 PBU 3.1.
1.04×10^{-6}
B4 PBU 3.1.
3.06×10^{-5}
B5 PBU 3.1.
6.76×10^{-4}

Failure on SAV-04 fail to close (PBU 3.1.)

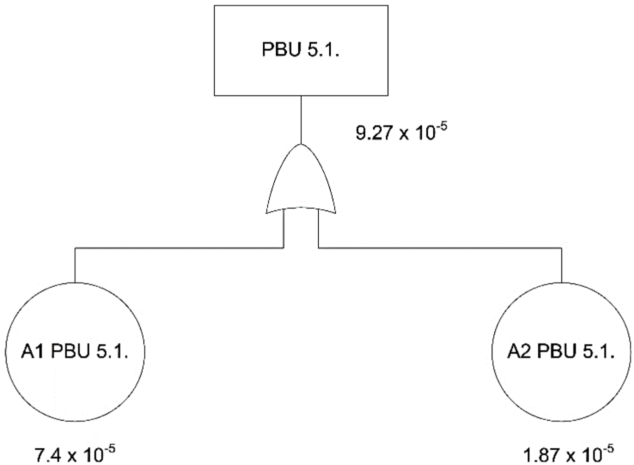
A1: Loss of power
A2: Delay
A3: Fail to close o demand
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop



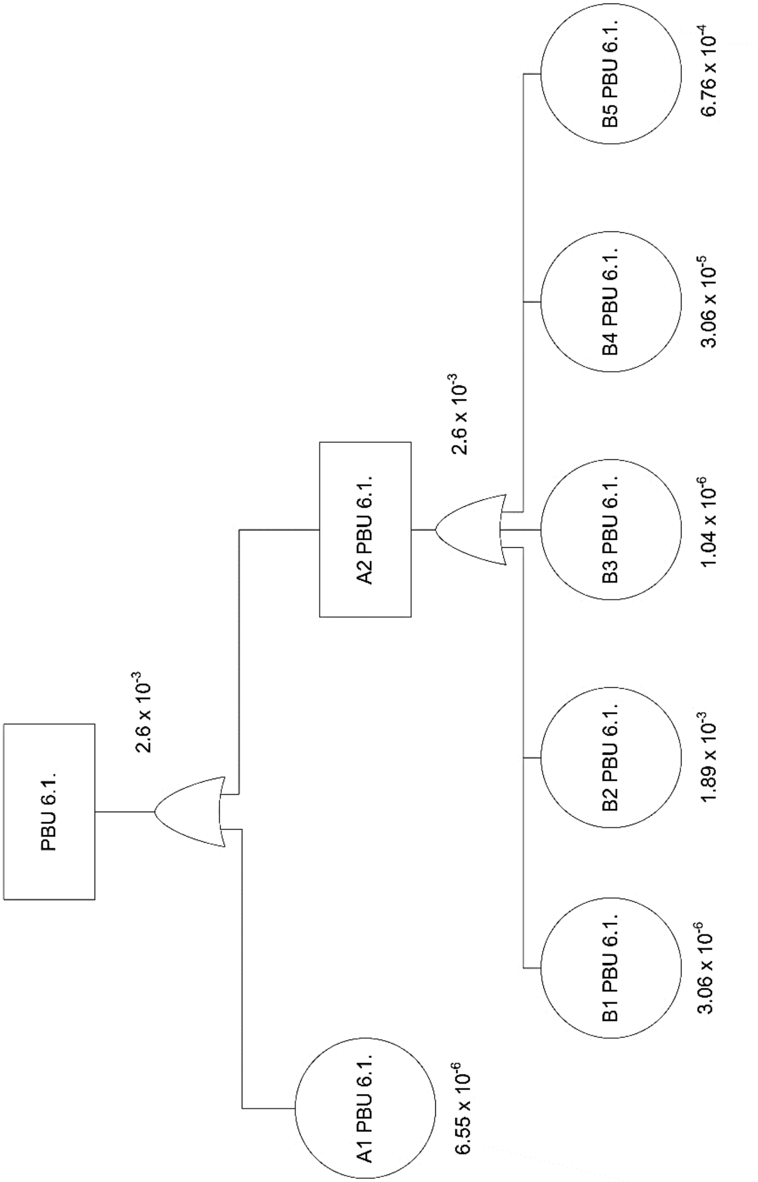
PBU 4.1.
2.6×10^{-3}
A2 PBU 4.1.
1×10^{-6}
A1 PBU 4.1.
2.6×10^{-3}
B3 PBU 4.1.
4.06×10^{-6}
C7 PBU 4.1.
3.14×10^{-6}
C6 PBU 4.1.
9.19×10^{-7}
B2 PBU 4.1.
1×10^{-6}
B1 PBU 4.1.
2.6×10^{-3}


B1 PBU 4.1.
2.6 x 10^-3
C1 PBU 4.1.
3.06 x 10^-6
C2 PBU 4.1.
1.89 x 10^-3
C3 PBU 4.1.
1.04 x 10^-6
C4 PBU 4.1.
3.06 x 10^-5
C5 PBU 4.1.
6.76 x 10^-4

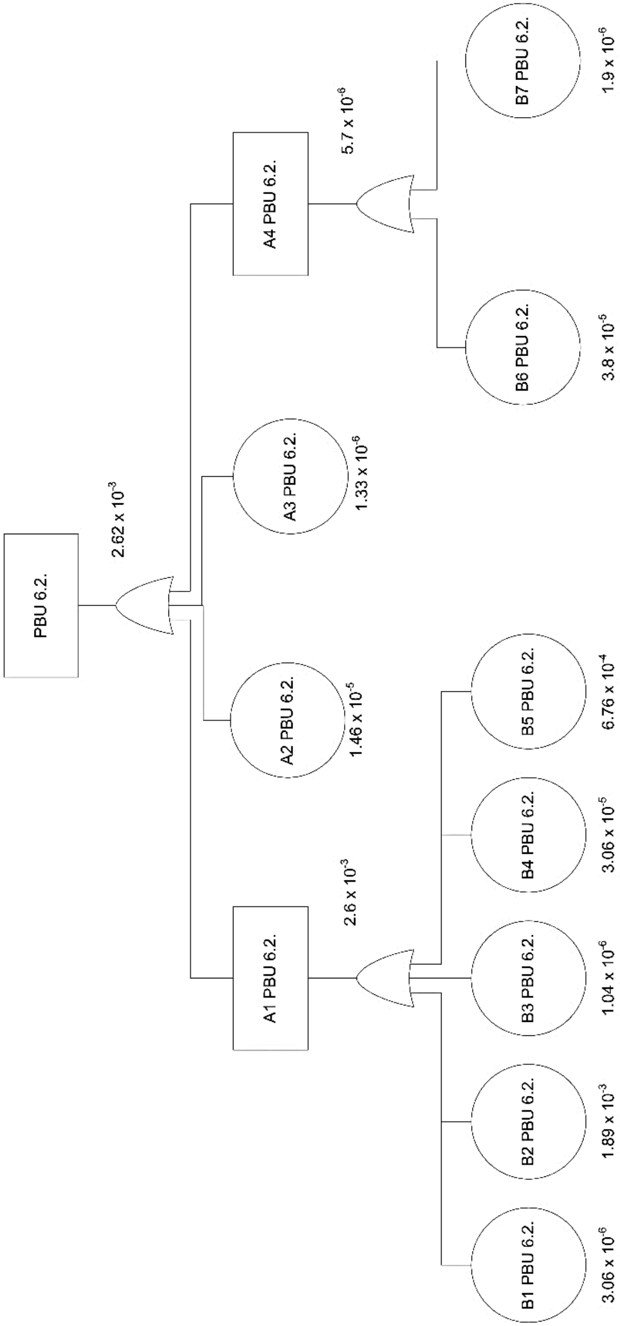
Failure on evaporate system (PBU 4.1.)
A1: Failure on pump
A2: Fail to regulate valve
B1: Loss of power
B2: Fail to start electric motor pump
B3: Pump is broken
C1: Breakdown
C2: Fail to start on demand
C3: Fail to synchronize
C4: Low output
C5: Spurious stop
C6: Fail to start pump
C7: Noise



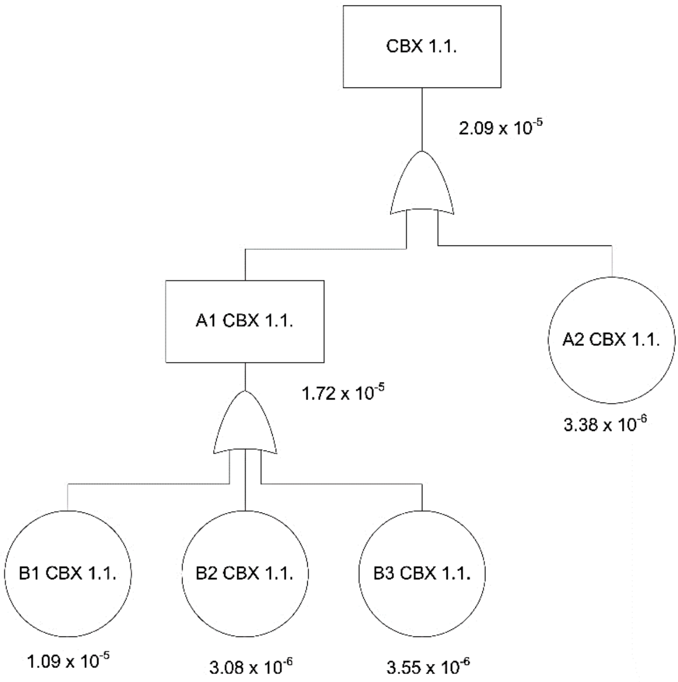
Leakage (PBU 5.1.)
A1: Pipe being rupture
A2: External leakage on valve


PBU 6.1.
2.6 x 10^-3
A1 PBU 6.1.
6.55 x 10^-6
A2 PBU 6.1.
2.6 x 10^-3
B1 PBU 6.1.
3.06 x 10^-6
B2 PBU 6.1.
1.89 x 10^-3
B3 PBU 6.1.
1.04 x 10^-6
B4 PBU 6.1.
3.06 x 10^-5
B5 PBU 6.1.
6.76 x 10^-4

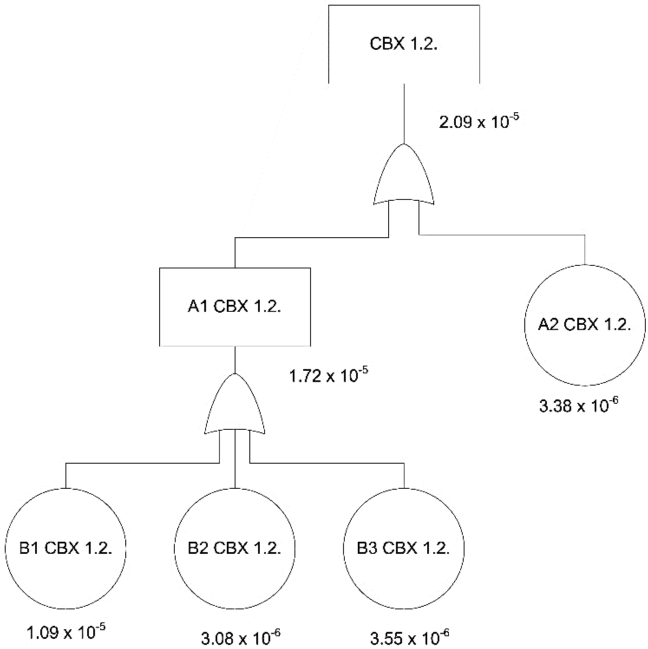
Fail to monitor pressure on the tank (PBU 6.1.)
A1: Failure on pressure sensor
A2: Loss of power
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop


PBU 6.2.
2.62 x 10-3
A1 PBU 6.2.
2.6 x 10-3
A2 PBU 6.2.
1.46 x 10-5
A3 PBU 6.2.
1.33 x 10-6
A4 PBU 6.2.
5.7 x 10-6
B1 PBU 6.2.
3.06 x 10-6
B2 PBU 6.2.
1.89 x 10-3
B3 PBU 6.2.
1.04 x 10-6
B4 PBU 6.2.
3.06 x 10-5
B5 PBU 6.2.
6.76 x 10-4
B6 PBU 6.2.
3.8 x 10-5
B7 PBU 6.2.
1.9 x 10-6

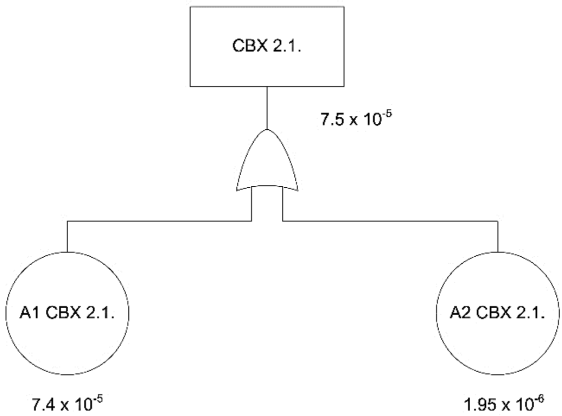
Failure on SAV-05 valve, fail to close (PBU 6.2.)
A1: Loss of power
A2: Internal leakage on valve
A3: Delay
A4: Fail to control valve
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Fail to close
B7: Structural deficiency



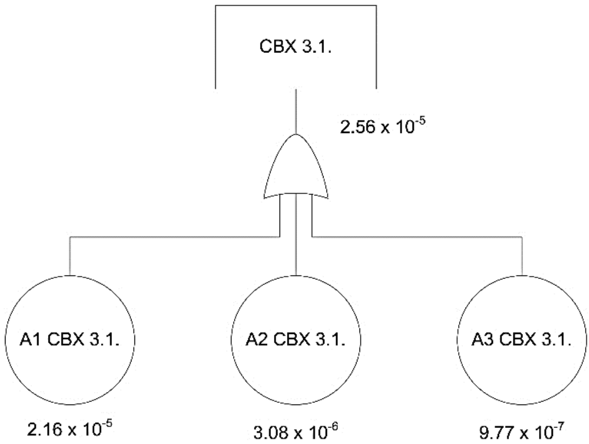
Failure on SAV-06 valve, cannot open (CBX 1.1.)
A1: Fail to regulate
A2: Delay
B1: Fail to open
B2: Structural deficiency
B3: Abnormal instrument reading



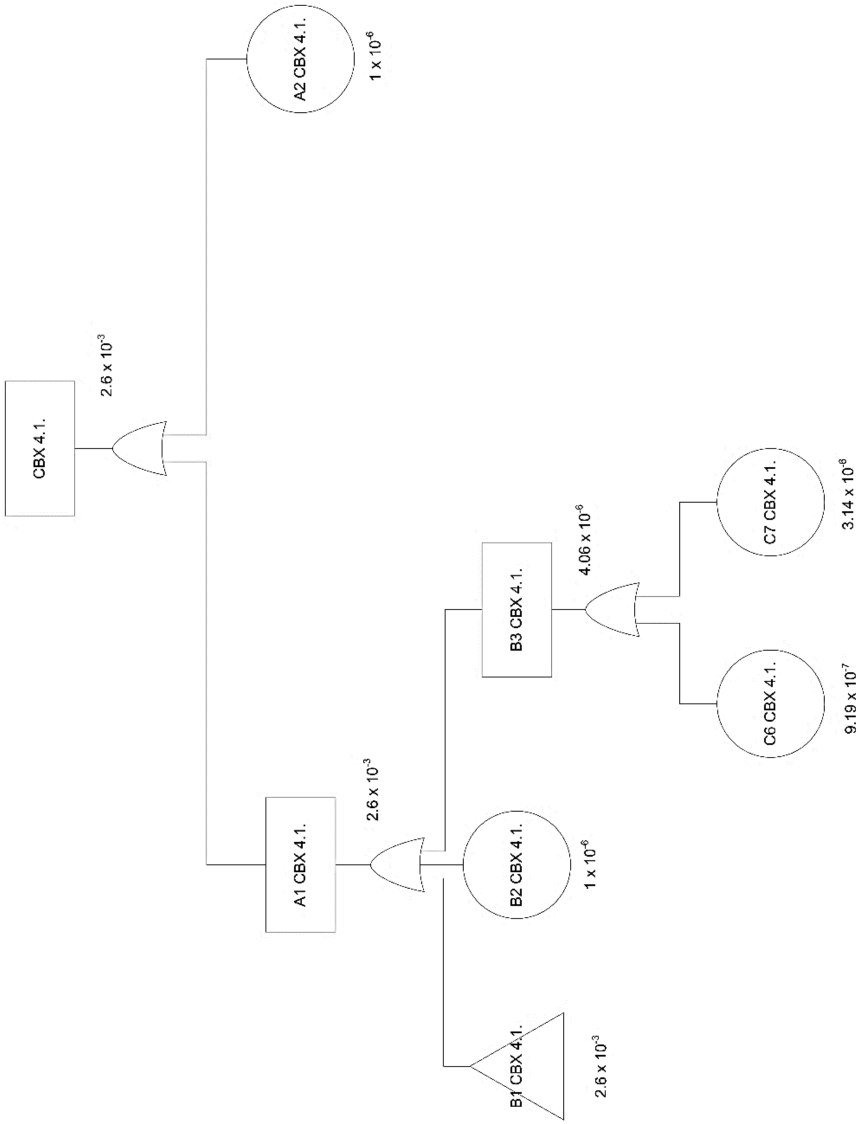
Failure on SAV-07 valve, cannot open (CBX 1.2.)
A1: Fail to regulate
A2: Delay
B1: Fail to open
B2: Structural deficiency
B3: Abnormal instrument reading

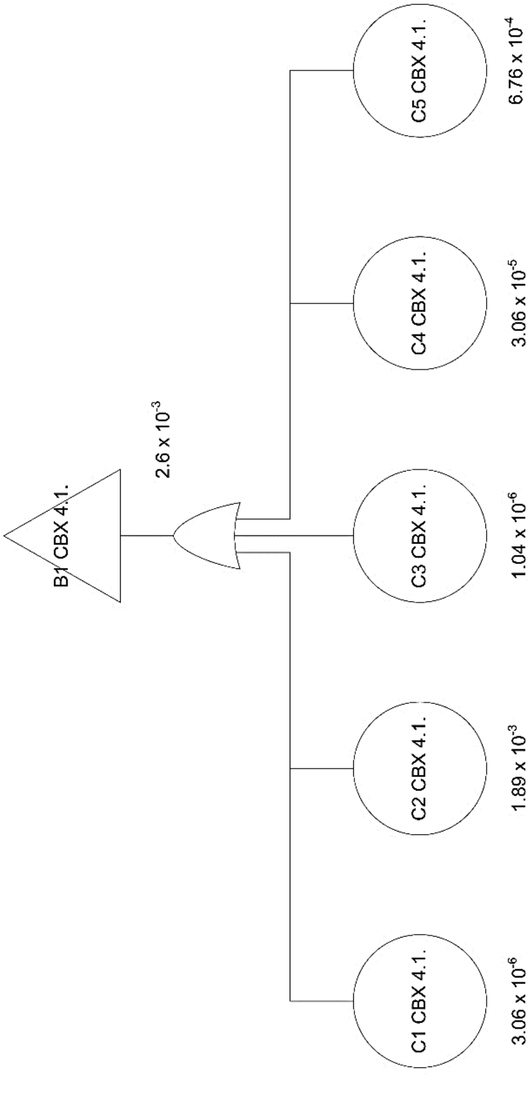


Leakage (CBX2.1.)
A1: Pipe being rupture
A2: External leakage on valve

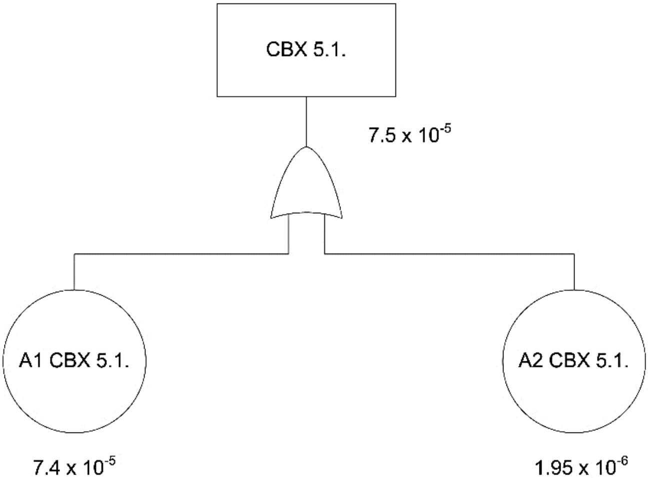


Failure on SAV-07 valve, fail to close (CBX 3.1.)
A1: Fail to close on demand
A2: Structural deficiency
A3: Valve leakage in closed position

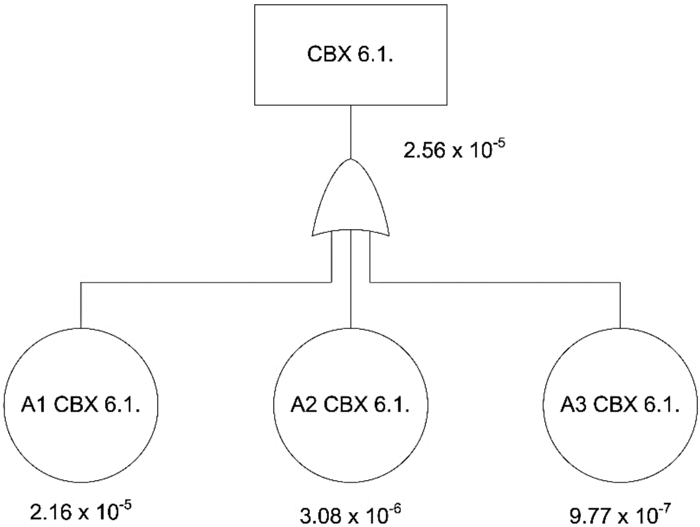

CBX 4.1.
2.6 x 10^{-3}
A2 CBX 4.1.
1 x 10^{-6}
A1 CBX 4.1.
2.6 x 10^{-3}
B3 CBX 4.1.
4.06 x 10^{-6}
C7 CBX 4.1.
3.14 x 10^{-6}
C6 CBX 4.1.
9.19 x 10^{-7}
B2 CBX 4.1.
1 x 10^{-6}
B1 CBX 4.1.
2.6 x 10^{-3}


B1 CBX 4.1.
2.6 x 10^-3
C1 CBX 4.1.
3.06 x 10^-6
C2 CBX 4.1.
1.89 x 10^-3
C3 CBX 4.1.
1.04 x 10^-6
C4 CBX 4.1.
3.06 x 10^-5
C5 CBX 4.1.
6.76 x 10^-4

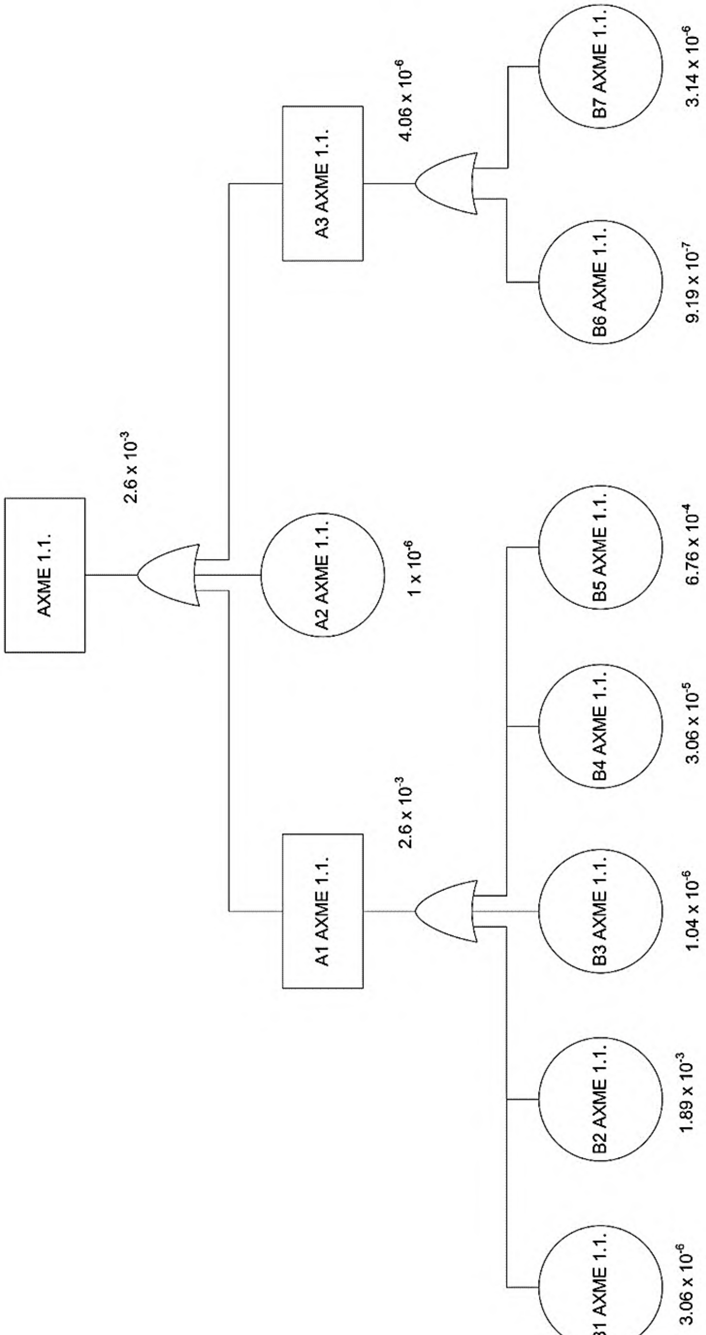
Failure on evaporate system (CBX 4.1.)
A1: Failure on pump
A2: Fail to regulate valve
B1: Loss of power
B2: Fail to start electric motor pump
B3: Pump is broken
C1: Breakdown
C2: Fail to start on demand
C3: Fail to synchronize
C4: Low output
C5: Spurious stop
C6: Fail to start pump
C7: Noise



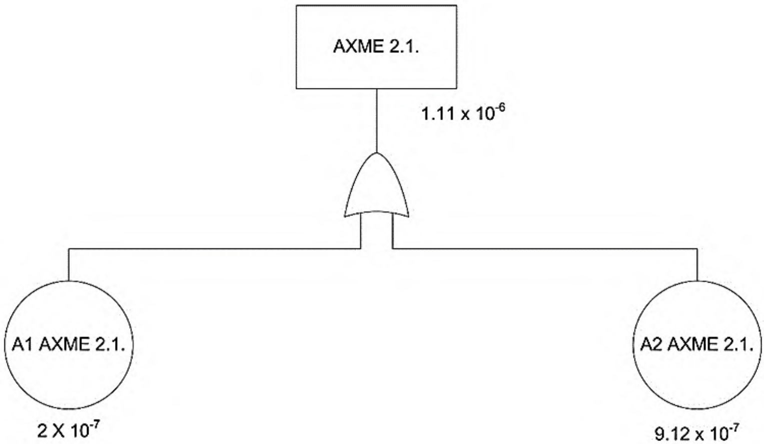
Leakage (CBX 5.1.)
A1: Pipe being rupture
A2: External leakage on valve



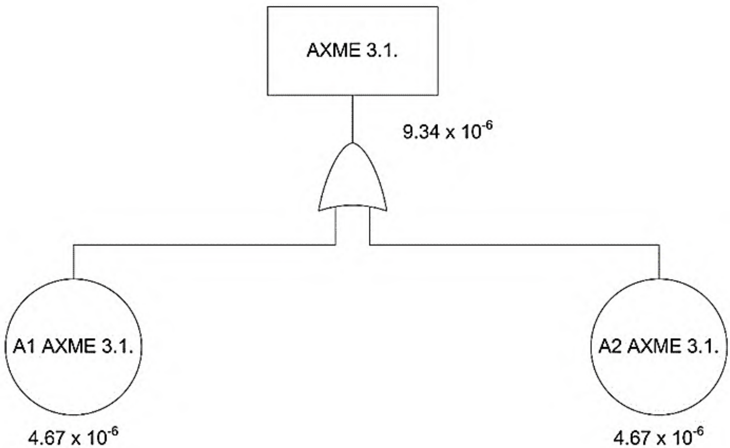
Failure on SAV-07 valve, fail to close (CBX 6.1.)
A1: Fail to close on demand
A2: Structural deficiency
A3: Valve leakage in closed position


AXME 1.1.
2.6 x 10^-3
A1 AXME 1.1.
2.6 x 10^-3
A2 AXME 1.1.
1 x 10^-6
A3 AXME 1.1.
4.06 x 10^-6
B1 AXME 1.1.
3.06 x 10^-6
B2 AXME 1.1.
1.89 x 10^-3
B3 AXME 1.1.
1.04 x 10^-6
B4 AXME 1.1.
3.06 x 10^-5
B5 AXME 1.1.
6.76 x 10^-4
B6 AXME 1.1.
9.19 x 10^-7
B7 AXME 1.1.
3.14 x 10^-6

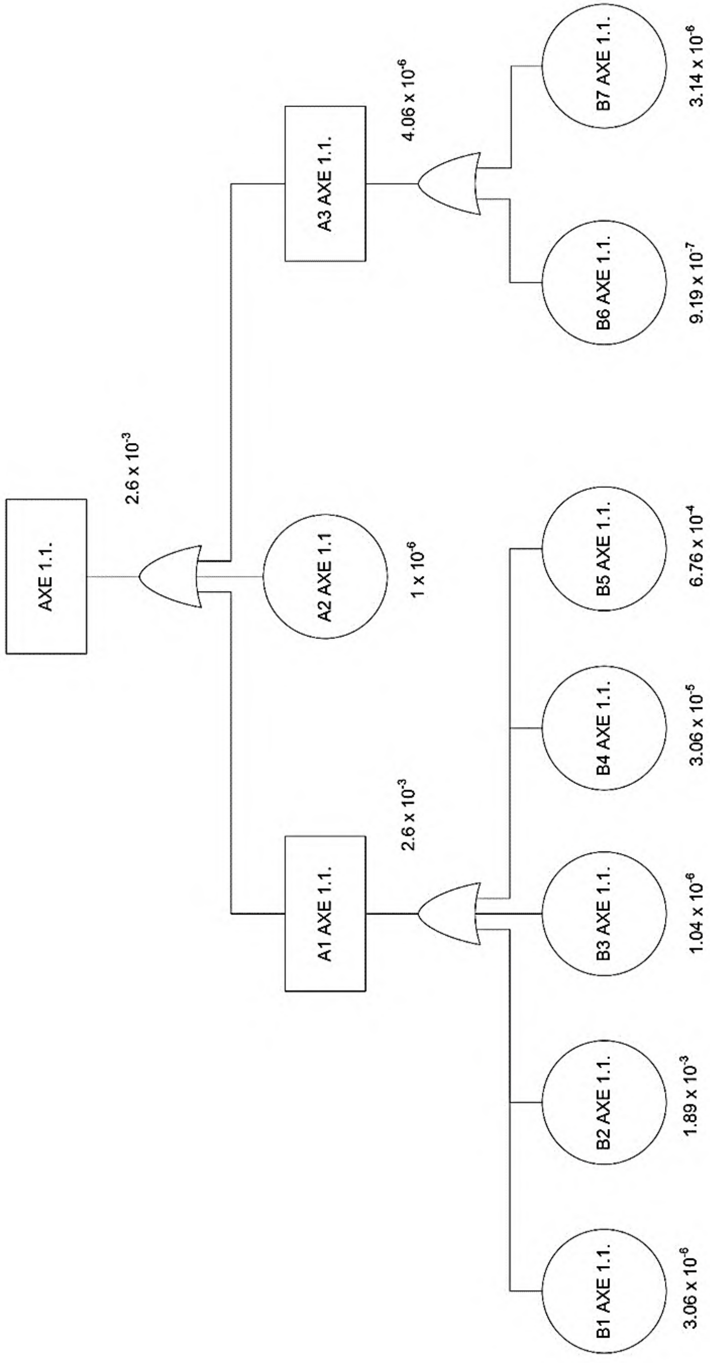
Failure on pump (AXME 1.1.)
A1: Loss of power
A2: Electric motor pump broken
A3: Fail on pump
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Fail to start on demand
B7: Noise



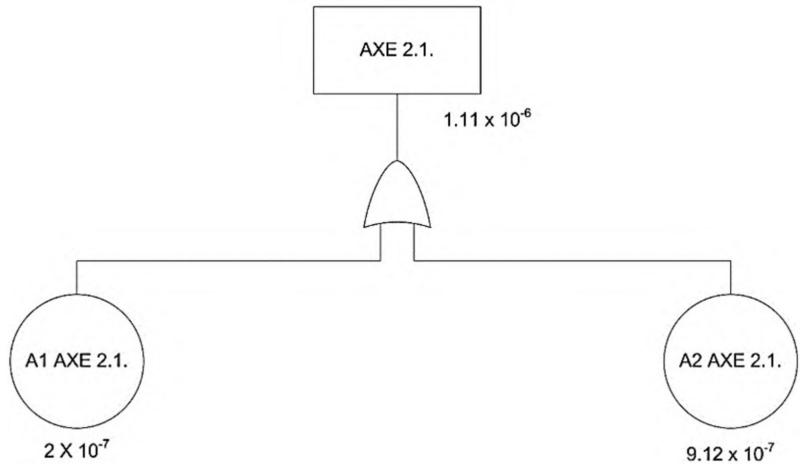
Leakage (AXME 2.1.)
A1: Pipe being rupture
A2: External leakage on valve



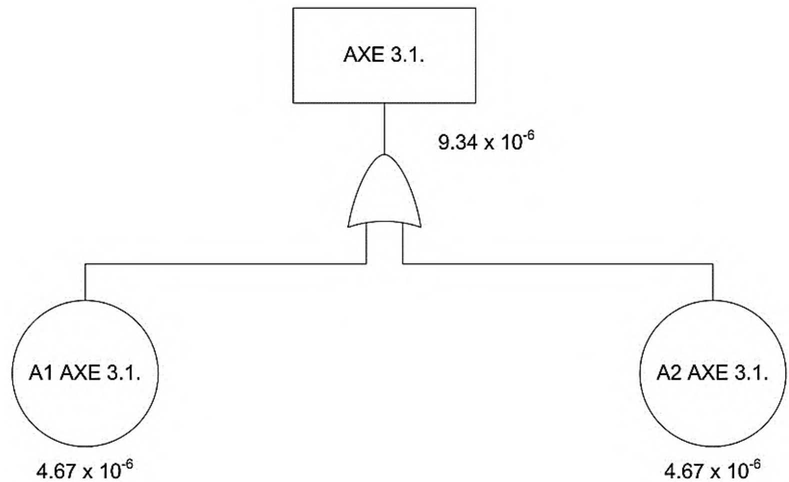
Failure on temperature sensors (AXME 3.1.)
A1: Fail to function on demand
A2: Spurious stop


AXE 1.1.
2.6 x 10-3
A1 AXE 1.1.
2.6 x 10-3
A2 AXE 1.1
1 x 10-6
A3 AXE 1.1.
4.06 x 10-6
B1 AXE 1.1.
3.06 x 10-6
B2 AXE 1.1.
1.89 x 10-3
B3 AXE 1.1.
1.04 x 10-6
B4 AXE 1.1.
3.06 x 10-5
B5 AXE 1.1.
6.76 x 10-4
B6 AXE 1.1.
9.19 x 10-7
B7 AXE 1.1.
3.14 x 10-6

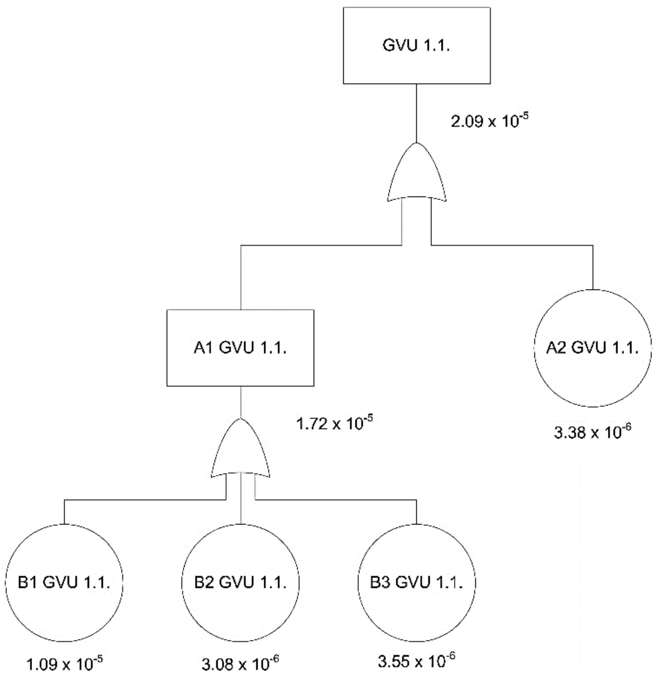
Failure on pump (AXE 1.1.)
A1: Loss of power
A2: Electric motor pump broken
A3: Fail on pump
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Fail to start on demand
B7: Noise



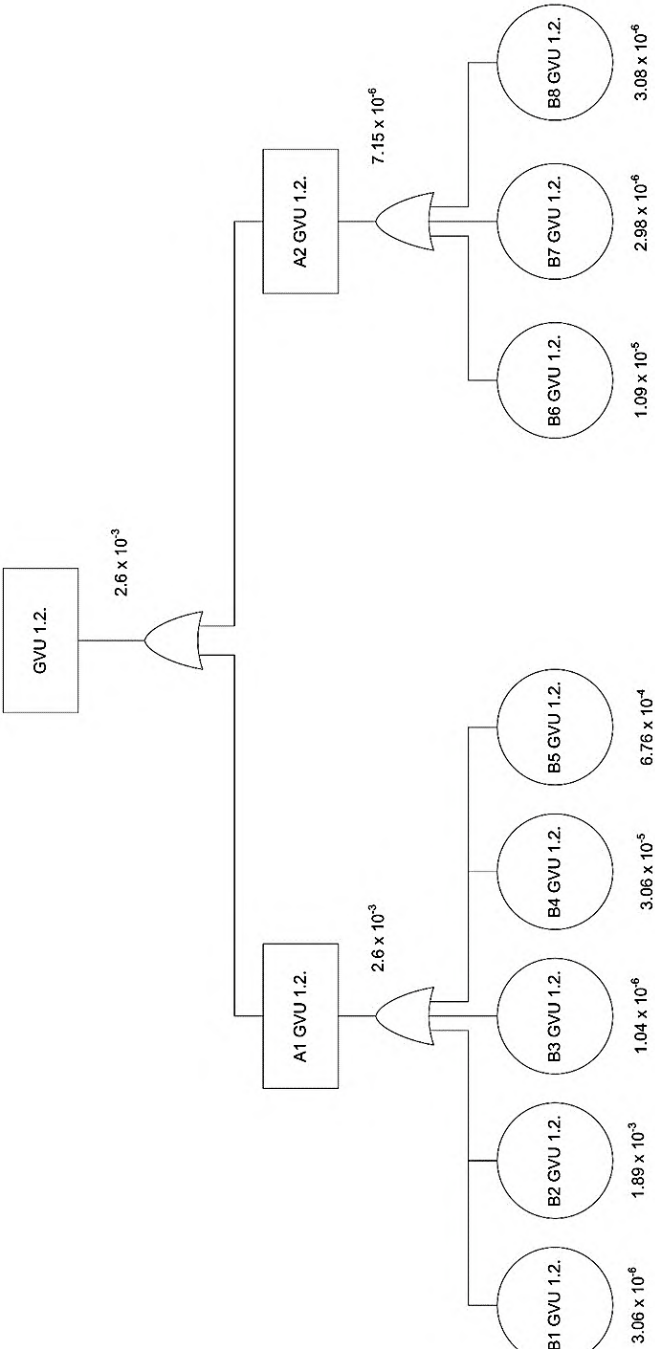
Leakage (AXE 2.1.)
A1: Pipe being rupture
A2: External leakage on valve



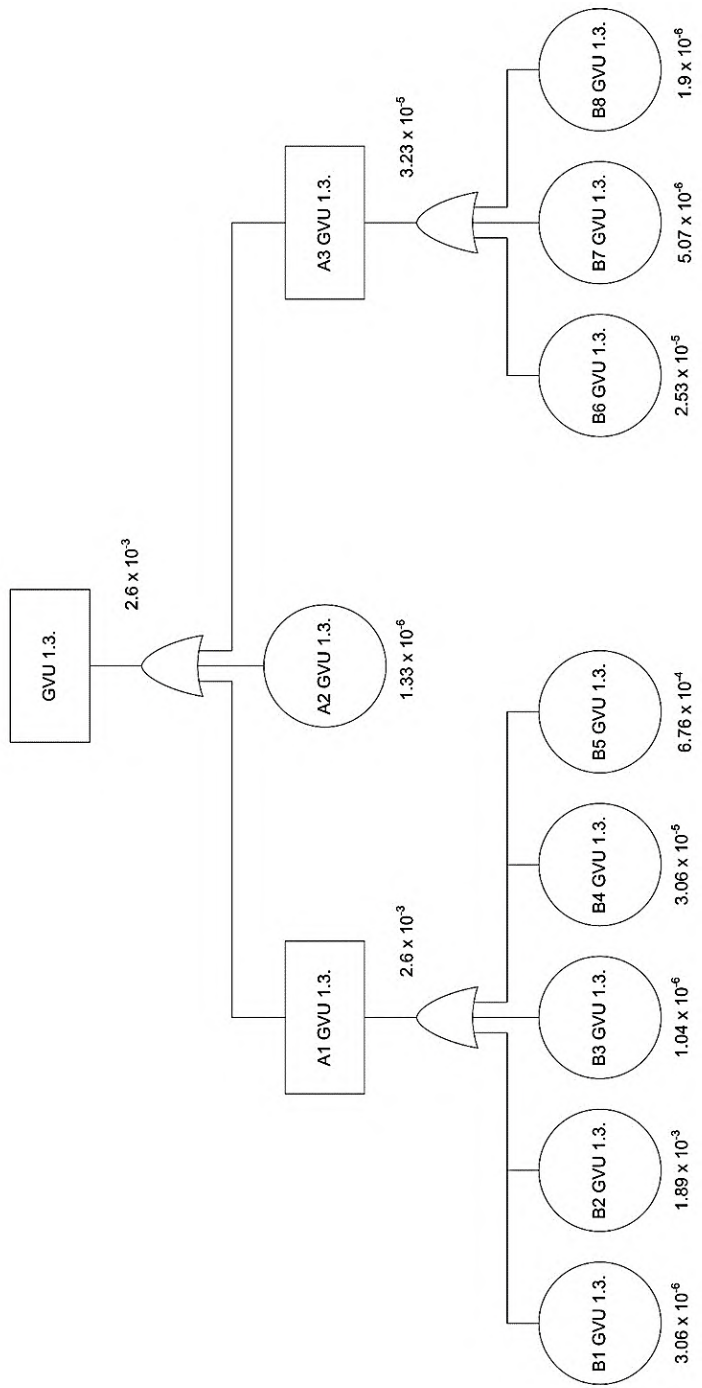
Failure on temperature sensors (AXE 3.1.)
A1: Fail to function on demand
A2: Spurious stop



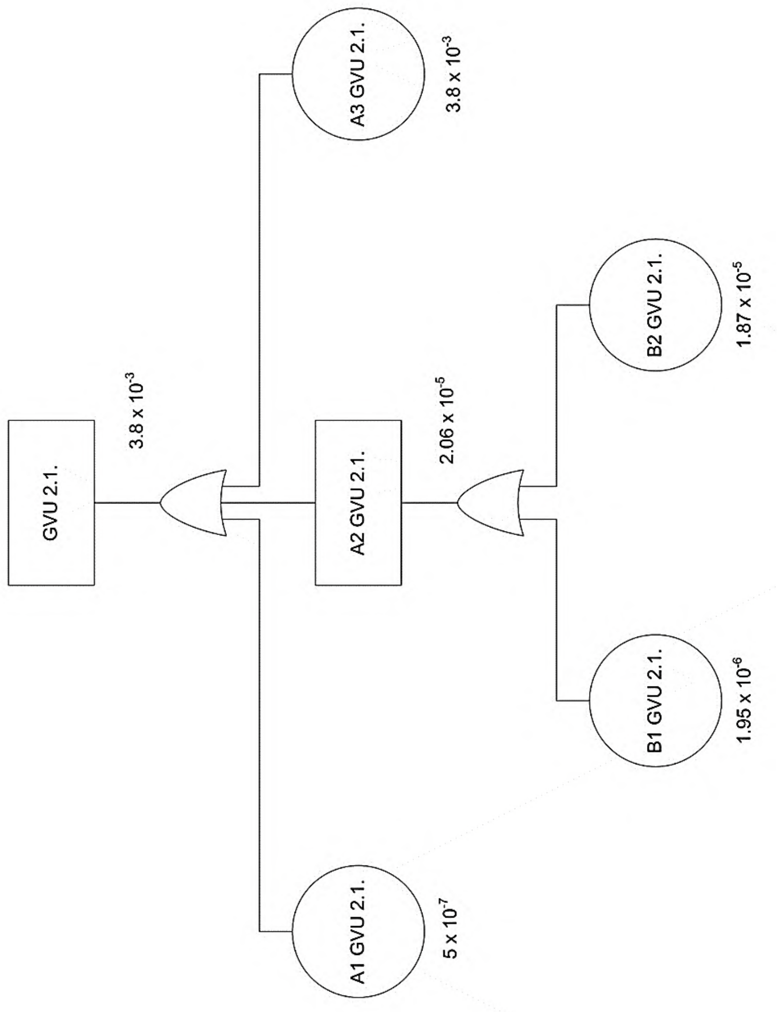
Failure on VSO-01 valve, fail to open (GVU 1.1.)
A1: Fail to regulate
A2: Delay
B1: Fail to open on demand
B2: Structural deficiency
B3: Abnormal instrument reading


GVU 1.2.
2.6 x 10^-3
A1 GVU 1.2.
2.6 x 10^-3
A2 GVU 1.2.
7.15 x 10^-6
B1 GVU 1.2.
3.06 x 10^-6
B2 GVU 1.2.
1.89 x 10^-3
B3 GVU 1.2.
1.04 x 10^-6
B4 GVU 1.2.
3.06 x 10^-5
B5 GVU 1.2.
6.76 x 10^-4
B6 GVU 1.2.
1.09 x 10^-5
B7 GVU 1.2.
2.98 x 10^-6
B8 GVU 1.2.
3.08 x 10^-6

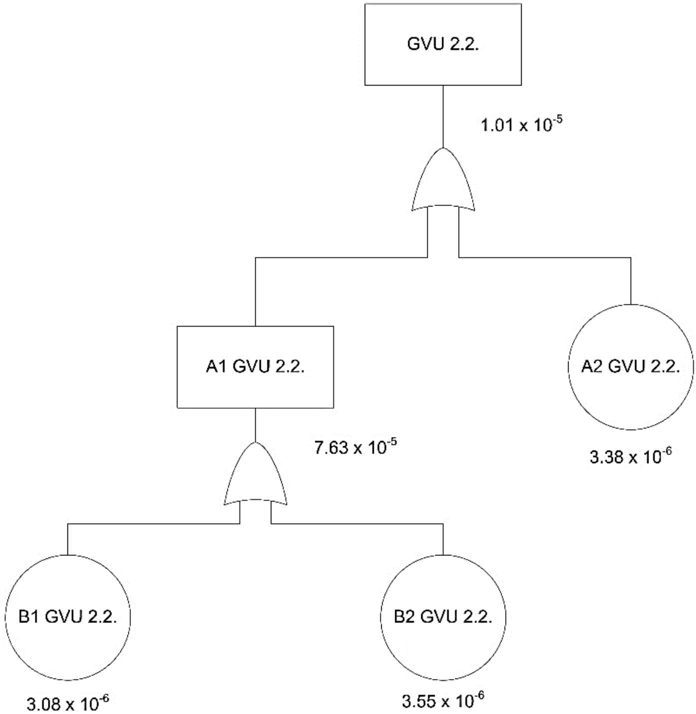
Failure VB-01 and VB-02 valve, fail to open (GVU 1.2.)
A1: Loss of power
A2: Fail to regulate valve
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Fail to open on demand
B7: Spurious stop
B8: Structural deficiency


GVU 1.3.
2.6×10^{-3}
A1 GVU 1.3.
2.6×10^{-3}
A2 GVU 1.3.
1.33×10^{-6}
A3 GVU 1.3.
3.23×10^{-5}
B1 GVU 1.3.
3.06×10^{-6}
B2 GVU 1.3.
1.89×10^{-3}
B3 GVU 1.3.
1.04×10^{-6}
B4 GVU 1.3.
3.06×10^{-5}
B5 GVU 1.3.
6.76×10^{-4}
B6 GVU 1.3.
2.53×10^{-5}
B7 GVU 1.3.
5.07×10^{-6}
B8 GVU 1.3.
1.9×10^{-6}

Failure on VG-01 valve, fail to open (GVU 1.3.)
A1: Loss of power
A2: Delay operation
A3: Fail to regulate valve
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Fail to open on demand
B7: Spurious stop
B8: Structural deficiency

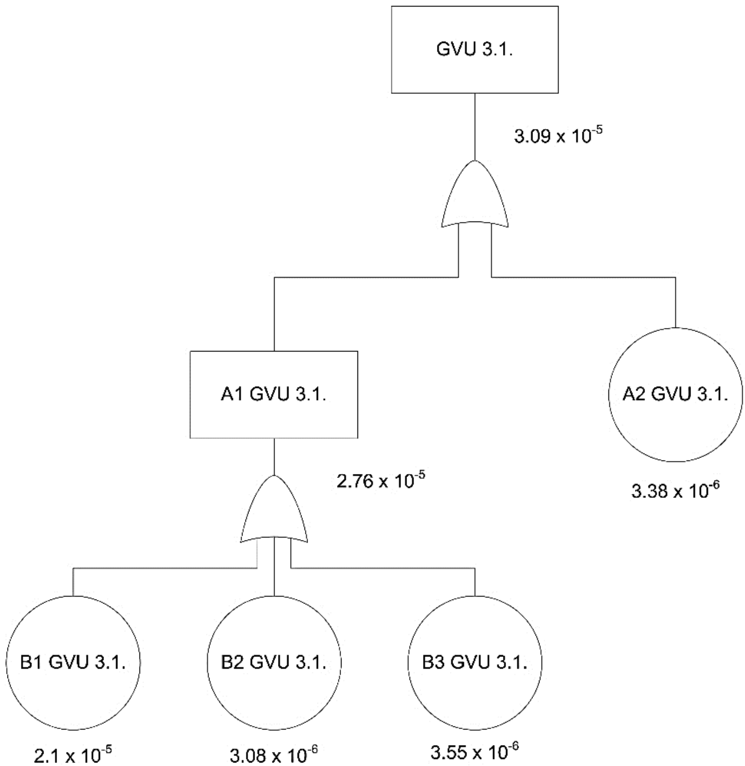

GVU 2.1.
3.8 x 10^{-3}
A3 GVU 2.1.
3.8 x 10^{-3}
A2 GVU 2.1.
2.06 x 10^{-5}
B2 GVU 2.1.
1.87 x 10^{-5}
B1 GVU 2.1.
1.95 x 10^{-6}
A1 GVU 2.1.
5 x 10^{-7}

Leakage (GVU 2.1.)
A1: Pipe being rupture
A2: Leakage on valve
A3: Leakage on filter
B1: Leakage on VSO or VB valve
B2: Leakage on VG valve

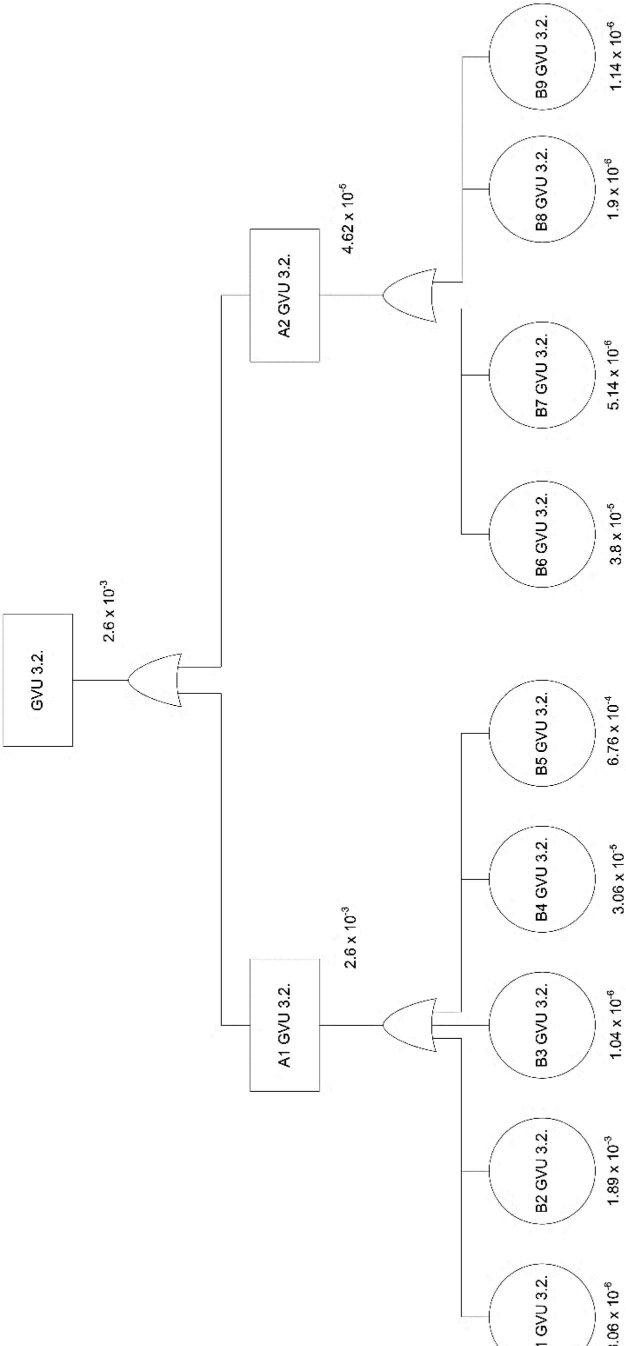


Failure on VG-01 valve, fail to regulate valve (GVU 2.2.)

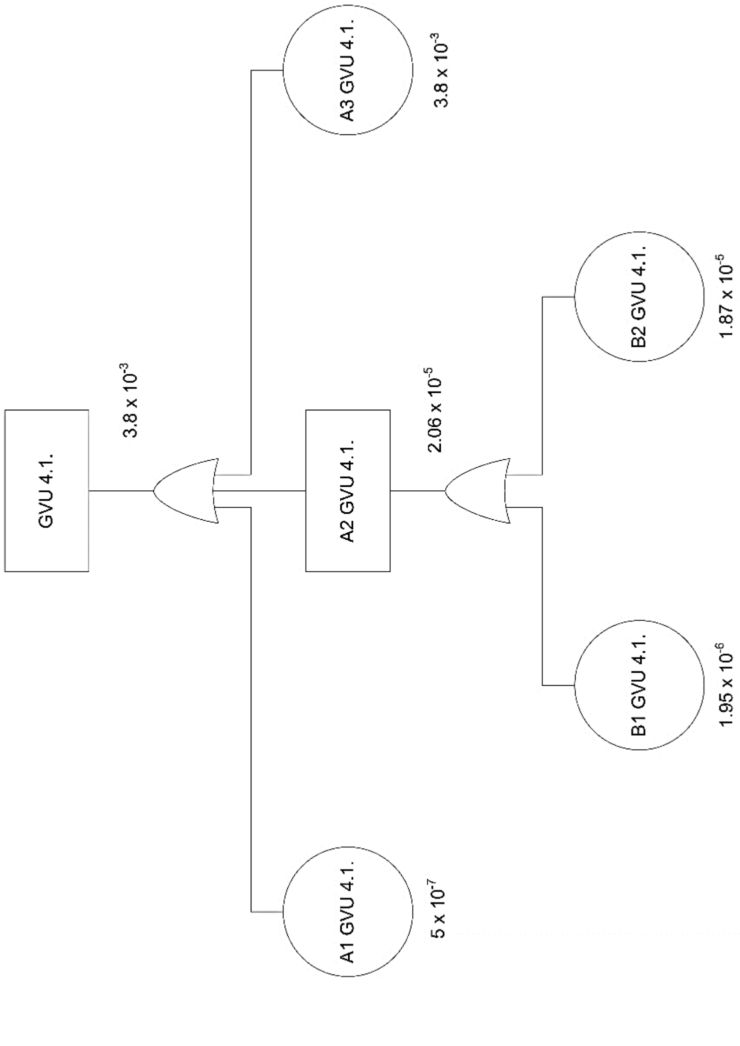
A1: Fail to regulate
A2: Delay
B1: Structural deficiency
B2: Abnormal instrument reading



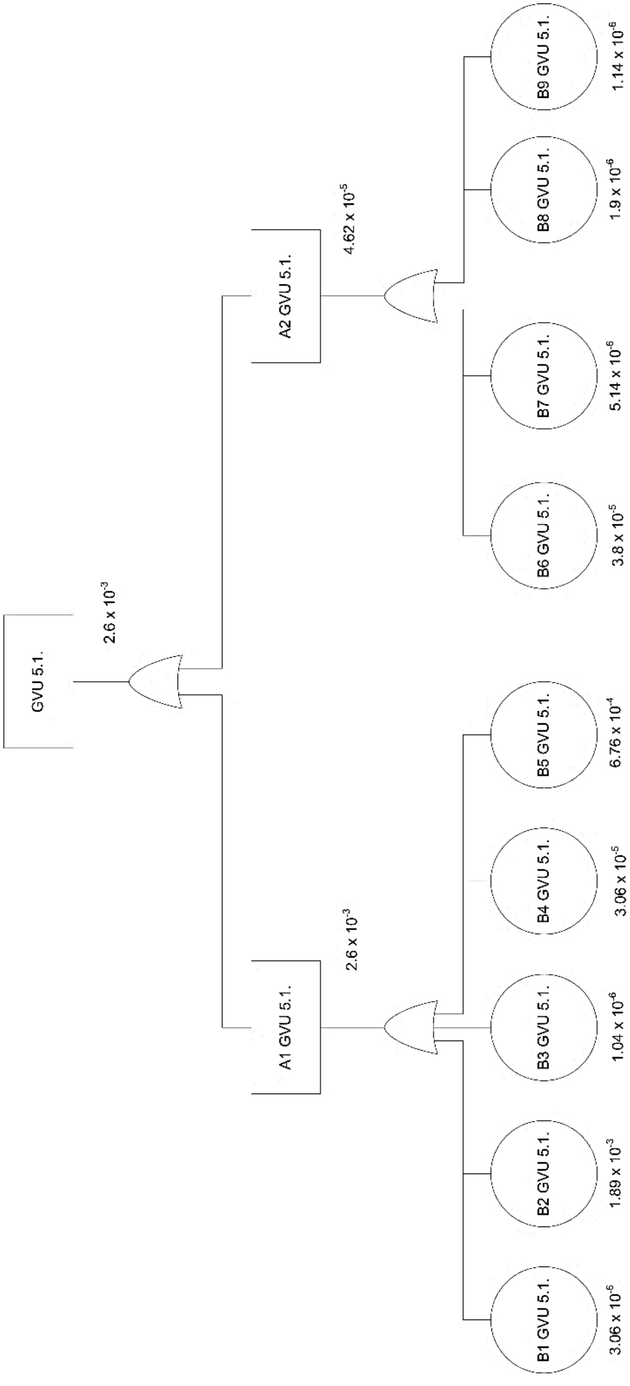
Failure on VSO-01 valve, fail to close (GVU 3.1.)
A1: Fail to regulate
A2: Delay
B1: Fail to close on demand
B2: Structural deficiency
B3: Abnormal instrument reading


GVU 3.2.
2.6×10^{-3}
A1 GVU 3.2.
2.6×10^{-3}
A2 GVU 3.2.
4.62×10^{-5}
B1 GVU 3.2.
3.06×10^{-6}
B2 GVU 3.2.
1.89×10^{-3}
B3 GVU 3.2.
1.04×10^{-6}
B4 GVU 3.2.
3.06×10^{-5}
B5 GVU 3.2.
6.76×10^{-4}
B6 GVU 3.2.
3.8×10^{-5}
B7 GVU 3.2.
5.14×10^{-6}
B8 GVU 3.2.
1.9×10^{-6}
B9 GVU 3.2.
1.14×10^{-6}

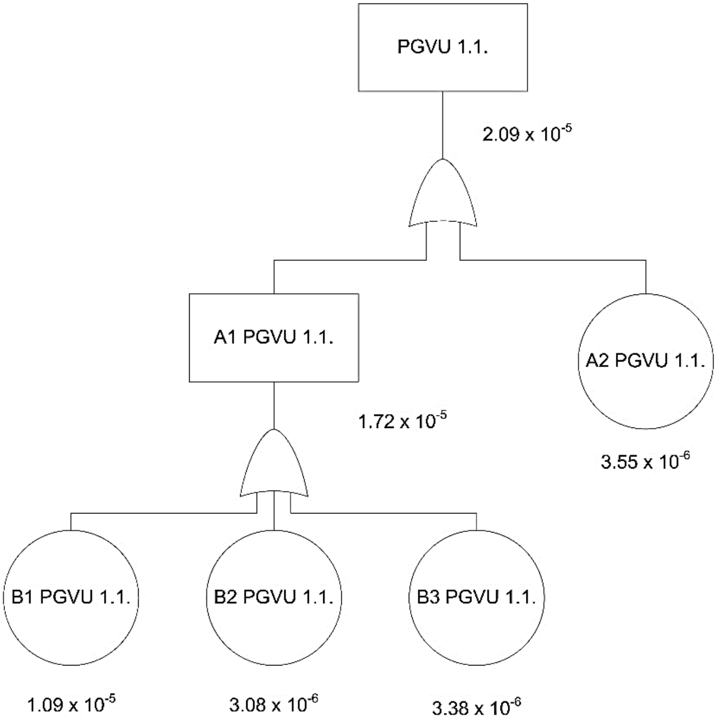
Failure on VG-01 Valve, fail to close (GVU 3.2.)
A1: Loss of power
A2: Fail to regulate
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Fail to close on demand
B7: Spurious operation
B8: Structural deficiency
B9: valve leakage in closed position


GVU 4.1.
3.8×10^{-3}
A2 GVU 4.1.
2.06×10^{-5}
A3 GVU 4.1.
3.8×10^{-3}
A1 GVU 4.1.
5×10^{-7}
B2 GVU 4.1.
1.87×10^{-5}
B1 GVU 4.1.
1.95×10^{-6}

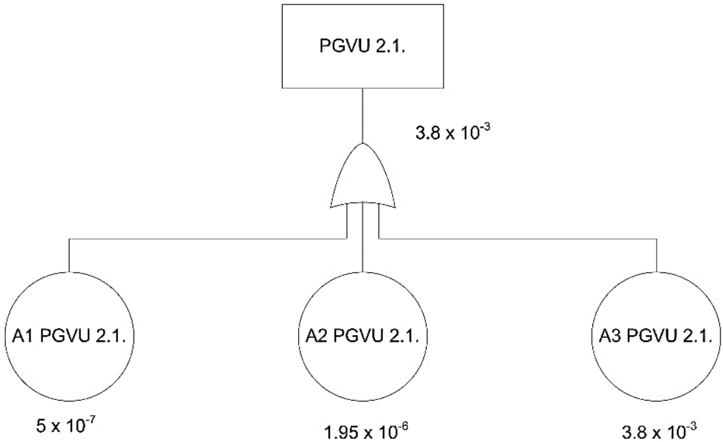
Leakage (GVU 4.1.)
A1: Pipe being rupture
A2: Leakage on valve
A3: Leakage on filter
B1: Leakage on VSO or VB valve
B2: Leakage on VG valve


GVU 5.1.
2.6×10^{-3}
A1 GVU 5.1.
2.6×10^{-3}
A2 GVU 5.1.
4.62×10^{-5}
B1 GVU 5.1.
3.06×10^{-6}
B2 GVU 5.1.
1.89×10^{-3}
B3 GVU 5.1.
1.04×10^{-6}
B4 GVU 5.1.
3.06×10^{-5}
B5 GVU 5.1.
6.76×10^{-4}
B6 GVU 5.1.
3.8×10^{-5}
B7 GVU 5.1.
5.14×10^{-6}
B8 GVU 5.1.
1.9×10^{-6}
B9 GVU 5.1.
1.14×10^{-6}

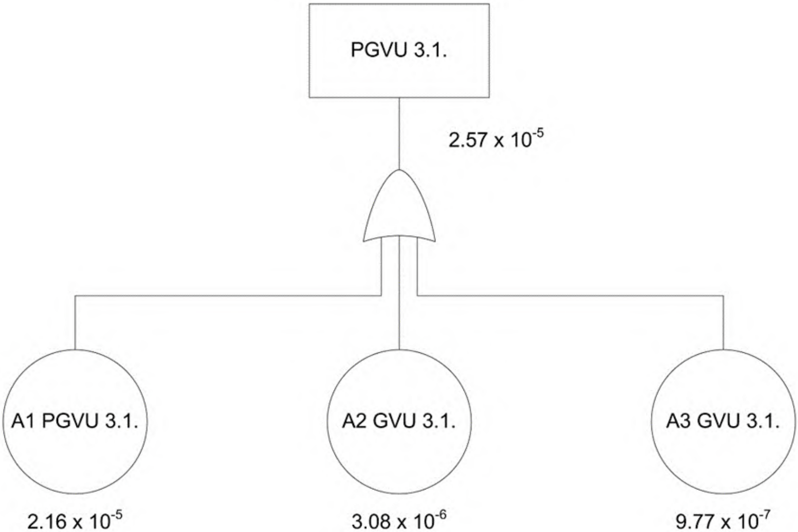
Failure on VG-01 Valve, fail to close (GVU 5.1.)
A1: Loss of power
A2: Fail to regulate
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Fail to close on demand
B7: Spurious operation
B8: Structural deficiency
B9: valve leakage in closed position



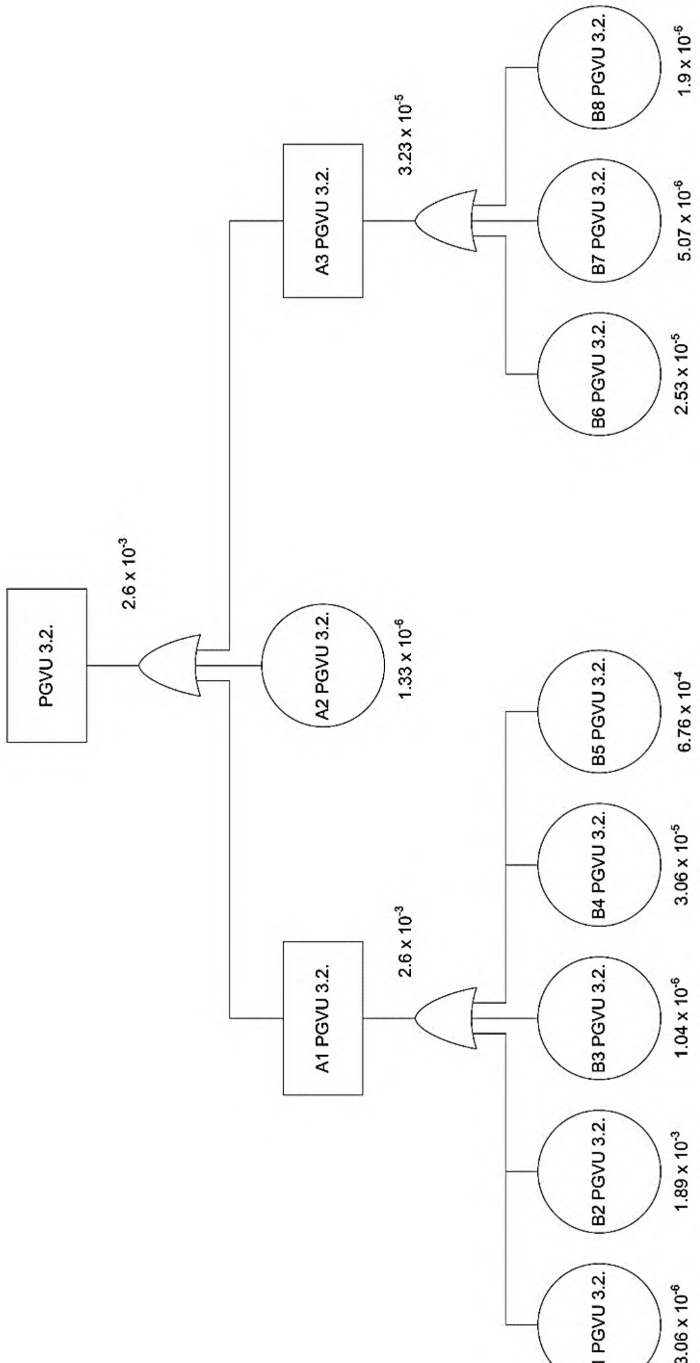
Failure on VSO-02 Valve, fail to open (PGVU 1.1.)
A1: Fail to regulate
A2: Delay
B1: Fail to open on demand
B2: Structural deficiency
B3: Abnormal instrument reading



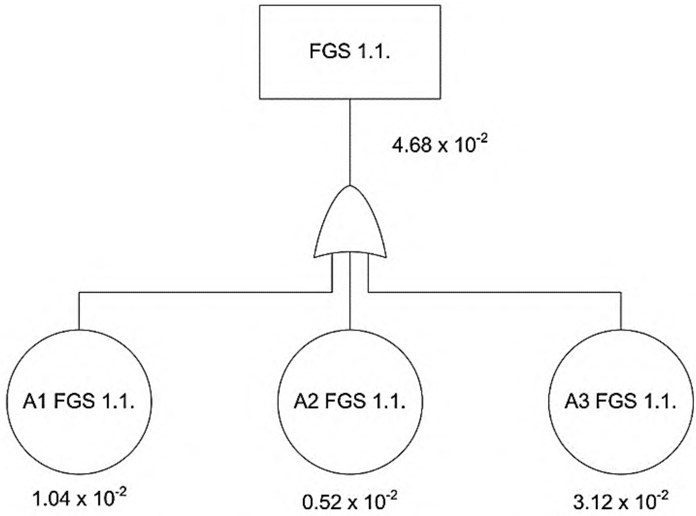
Leakage (PGVU 2.1.)
A1: Pipe being rupture
A2: Leakage on VSO valve
A3: Leakage on filter



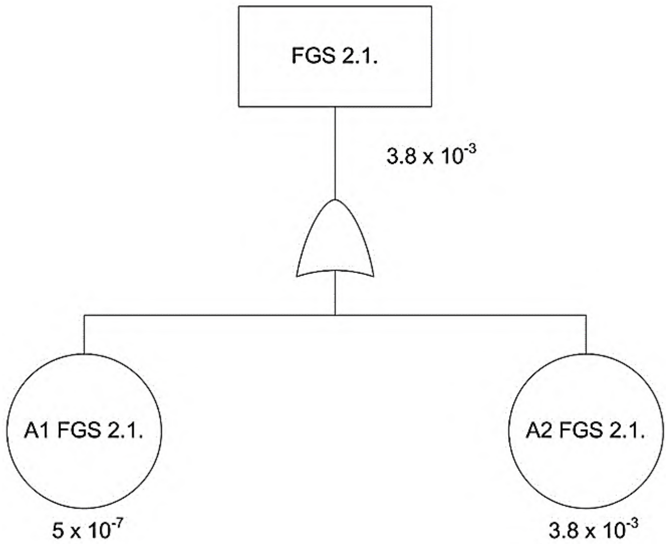
Failure on VSO-01 Valve, fail to close (PGVU 3.1.)
A1: Fail to close on demand
A2: Structural deficiency
A3: Valve leakage in closed position


PGVU 3.2.
2.6 x 10-3
A1 PGVU 3.2.
2.6 x 10-3
A2 PGVU 3.2.
1.33 x 10-6
A3 PGVU 3.2.
3.23 x 10-5
B1 PGVU 3.2.
3.06 x 10-6
B2 PGVU 3.2.
1.89 x 10-3
B3 PGVU 3.2.
1.04 x 10-6
B4 PGVU 3.2.
3.06 x 10-5
B5 PGVU 3.2.
6.76 x 10-4
B6 PGVU 3.2.
2.53 x 10-5
B7 PGVU 3.2.
5.07 x 10-6
B8 PGVU 3.2.
1.9 x 10-6

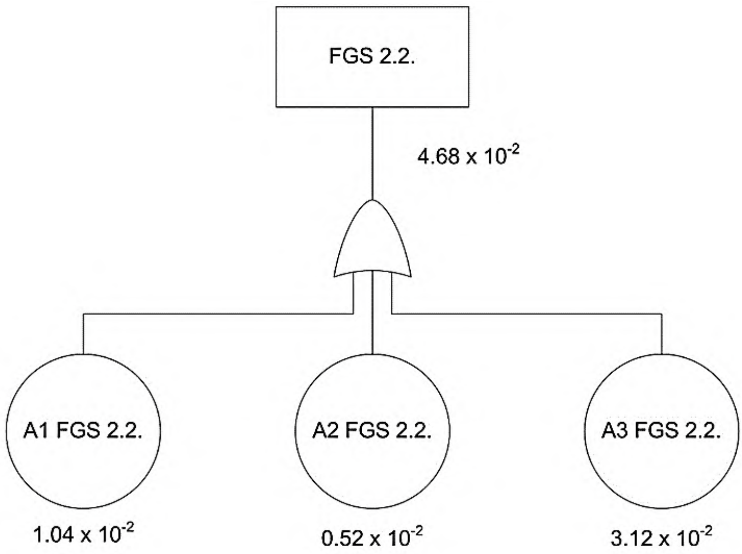
Failure on VV-01 or VV-02 valve, fail to open (PGVU 3.2.)
A1: Loss of power
A2: Delay operation
A3: Fail to regulate valve
B1: Breakdown
B2: Fail to start on demand
B3: Fail to synchronize
B4: Low output
B5: Spurious stop
B6: Fail to open on demand
B7: Spurious stop
B8: Structural deficiency



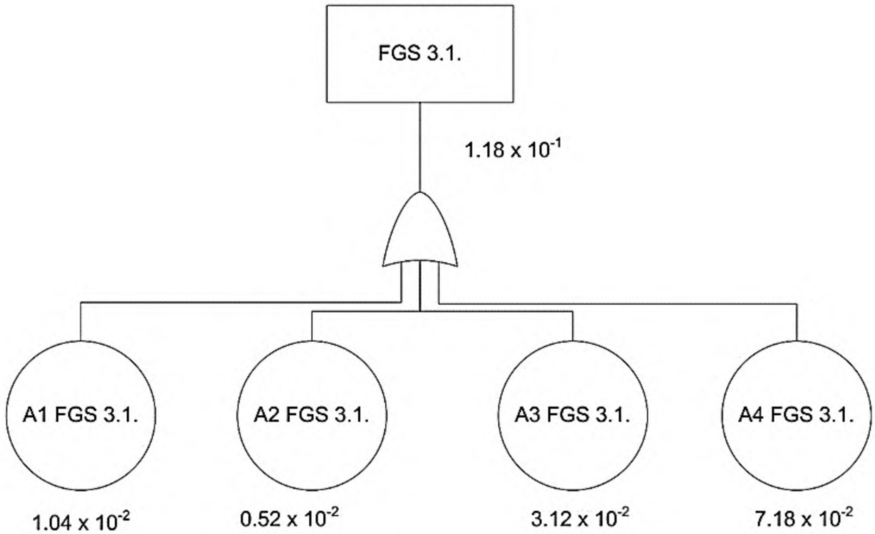
Failure on gas admission valve, cannot flow LNG vapor (FGS 1.1.)
A1: Failure on actuating device
A2: Failure on injection
A3: Failure on control



Leakage (FGS 2.1.)
A1: Pipe being rupture
A2: Leakage on filter



Failure on gas admission valve, cannot flow LNG vapor (FGS 2.1.)
A1: Failure on actuating device
A2: Failure on injection
A3: Failure on control



Failure on gas admission valve, cannot flow LNG vapor (FGS 3.1.)
A1: Failure on actuating device
A2: Failure on injection
A3: Failure on control
A4: Leakage

CONSEQUNECE ANALYSIS USING ALOHA

1. Consequence analysis: Explosion on tank

CHEMICAL DATA:

- Chemical Name: METHANE
- CAS Number: 74-82-8
- Molecular Weight: 16.04 g/mol
- PAC-1: 65000 ppm
- PAC-2: 230000 ppm
- PAC-3: 400000 ppm
- LEL: 50000 ppm
- UEL: 150000 ppm
- Ambient Boiling Point: -258.7° F
- Vapor Pressure at Ambient Temperature: greater than 1 atm
- Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)

- Wind: 20 miles/hour from NNW at 3 meters
- Ground Roughness: open water
- Cloud Cover: 0 tenths
- Air Temperature: 16° C
- Stability Class: E
- No Inversion Height
- Relative Humidity: 75%

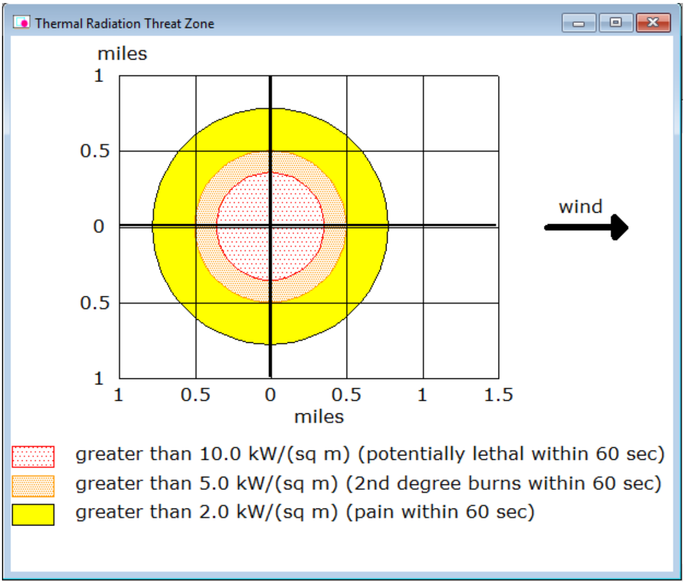
SOURCE STRENGTH:

- BLEVE of flammable liquid in horizontal cylindrical tank
- Tank Diameter: 4.3 meters
- Tank Length: 13.8 meters
- Tank Volume: 200 cubic meters

- Tank contains liquid
- Internal Storage Temperature: -161° C
- Chemical Mass in Tank: 75,958 kilograms
- Tank is 90% full
- Internal Pressure at Failure: 20 atmospheres
- Percentage of Tank Mass in Fireball: 100.0%
- Fireball Diameter: 269 yards
- Burn Duration: 15 seconds

THREAT ZONE:

- Threat Modeled: Thermal radiation from fireball
- Red : 622 yards --- (10.0 kW/(sq m) = potentially lethal within 60 sec)
- Orange: 877 yards --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)
- Yellow: 1366 yards --- (2.0 kW/(sq m) = pain within 60 sec)



2. Consequence analysis: Explosion on Cool Box

CHEMICAL DATA:

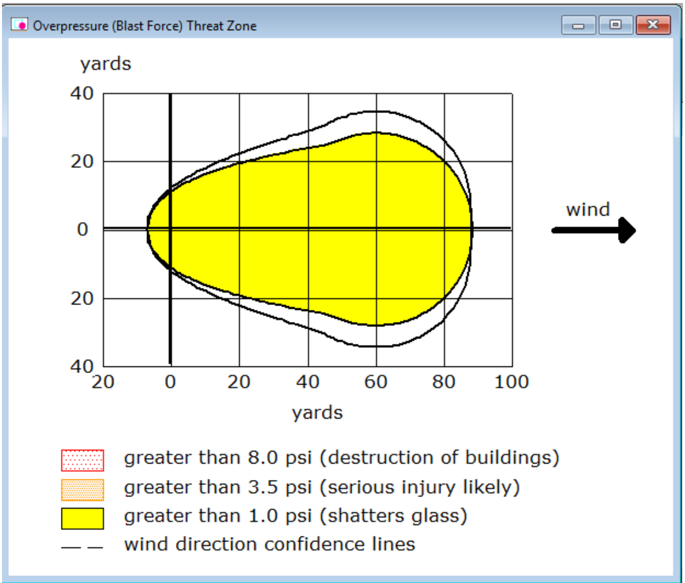
- Chemical Name: METHANE
- CAS Number: 74-82-8
- Molecular Weight: 16.04 g/mol
- PAC-1: 65000 ppm
- PAC-2: 230000 ppm
- PAC-3: 400000 ppm
- LEL: 50000 ppm
- UEL: 150000 ppm
- Ambient Boiling Point: -258.7° F
- Vapor Pressure at Ambient Temperature: greater than 1 atm
- Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
- Wind: 20 miles/hour from NNW at 3 meters
- Ground Roughness: open water
- Cloud Cover: 0 tenths
- Air Temperature: 16° C
- Stability Class: E
- No Inversion Height
- Relative Humidity: 75%

SOURCE STRENGTH:
- Leak from short pipe or valve in horizontal cylindrical tank
- Flammable chemical escaping from tank (not burning)
- Tank Diameter: 4.3 meters
- Tank Length: 13.8 meters
- Tank Volume: 200 cubic meters
- Tank contains liquid
- Internal Temperature: -161° C
- Chemical Mass in Tank: 75,958 kilograms
- Tank is 90% full
- Circular Opening Diameter: 11.43 centimeters
- Opening is 4.00 meters from tank bottom
- Release Duration: 49 minutes
- Max Average Sustained Release Rate: 1,340 pounds/min (averaged over a minute or more)
- Total Amount Released: 44,656 pounds
  Note: The chemical escaped as a mixture of gas and aerosol (two phase flow).

THREAT ZONE:
- Threat Modeled: Overpressure (blast force) from vapor cloud explosion
- Type of Ignition: ignited by spark or flame

- Level of Congestion: congested
- Model Run: Heavy Gas
- Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
- Orange: LOC was never exceeded --- (3.5 psi = serious injury likely)
- Yellow: 89 yards --- (1.0 psi = shatters glass)



3. Consequence analysis: Leakage on Cool Box-GVU pipe (outdoor)

CHEMICAL DATA:

- Chemical Name: METHANE
- CAS Number: 74-82-8
- Molecular Weight: 16.04 g/mol
- PAC-1: 65000 ppm
- PAC-2: 230000 ppm
- PAC-3: 400000 ppm
- LEL: 50000 ppm
- UEL: 150000 ppm
- Ambient Boiling Point: -258.7° F
- Vapor Pressure at Ambient Temperature: greater than 1 atm
- Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)

- Wind: 20 miles/hour from NNW at 3 meters
- Ground Roughness: open water
- Cloud Cover: 0 tenths
- Air Temperature: 16° C
- Stability Class: E
- No Inversion Height
- Relative Humidity: 75%

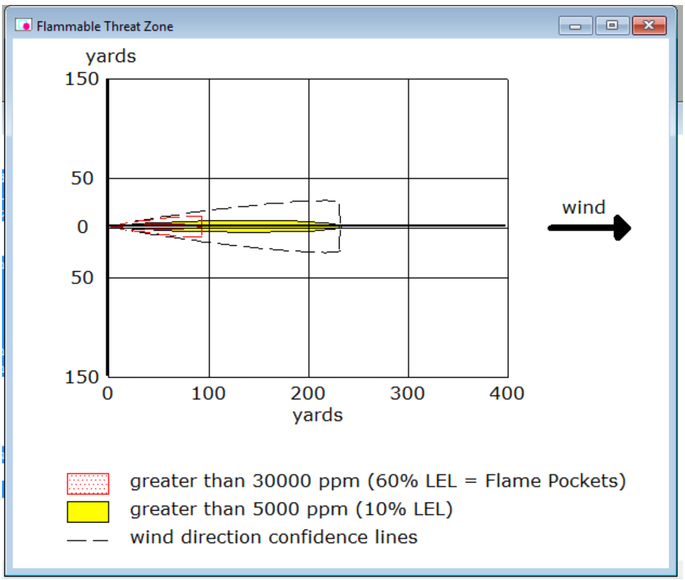
SOURCE STRENGTH:

- Flammable gas escaping from pipe (not burning)
- Pipe Diameter: 11.43 centimeters
- Pipe Length: 66 meters
- Unbroken end of the pipe is connected to an infinite source
- Pipe Roughness: smooth

- Hole Area: 103 sq cm
- Pipe Press: 592000 pascals
- Pipe Temperature: 60° C
- Release Duration: ALOHA limited the duration to 1 hour
- Max Average Sustained Release Rate: 488 pounds/min (averaged over a minute or more)
- Total Amount Released: 29,243 pounds

THREAT ZONE:

- Threat Modeled: Flammable Area of Vapor Cloud
- Model Run: Gaussian
- Red : 94 yards --- (30000 ppm = 60% LEL = Flame Pockets)
- Yellow: 234 yards --- (5000 ppm = 10% LEL)



4. Consequence analysis: Explosion on GVU

CHEMICAL DATA:

- Chemical Name: METHANE
- CAS Number: 74-82-8
- Molecular Weight: 16.04 g/mol
- PAC-1: 65000 ppm
- PAC-2: 230000 ppm
- PAC-3: 400000 ppm
- LEL: 50000 ppm
- UEL: 150000 ppm
- Ambient Boiling Point: -258.7° F
- Vapor Pressure at Ambient Temperature: greater than 1 atm
- Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)

- Wind: 20 miles/hour from nnw at 3 meters
- Ground Roughness: open water
- Cloud Cover: 0 tenths
- Air Temperature: 16° C
- Stability Class: E
- No Inversion Height
- Relative Humidity: 75%

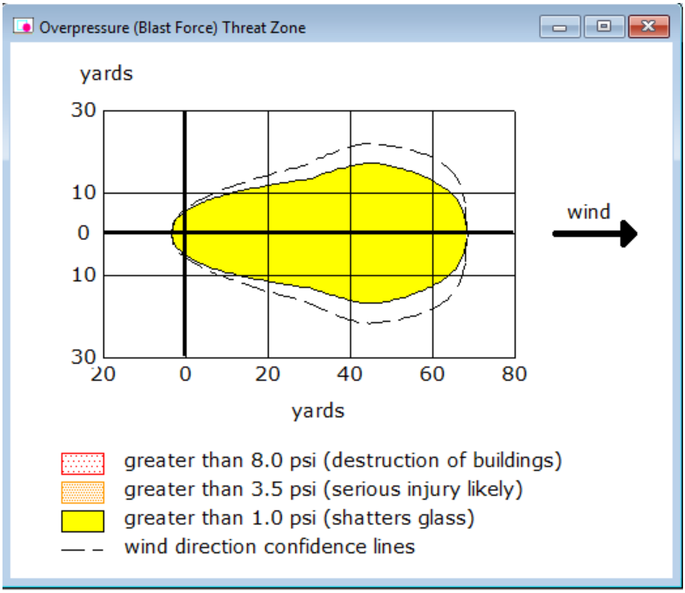
SOURCE STRENGTH:

- Leak from short pipe or valve in horizontal cylindrical tank
- Flammable chemical escaping from tank (not burning)
- Tank Diameter: 3.2 meters
- Tank Length: 2.71 meters
- Tank Volume: 21.8 cubic meters

- Tank contains gas only
- Internal Temperature: 0° C
- Chemical Mass in Tank: 0.28 tons
- Internal Press: 1600000 pascals
- Circular Opening Diameter: 11.43 centimeters
- Release Duration: 1 minute
- Max Average Sustained Release Rate: 8.47 pounds/sec (averaged over a minute or more)
- Total Amount Released: 508 pounds

THREAT ZONE:

- Threat Modeled: Overpressure (blast force) from vapor cloud explosion
- Type of Ignition: ignited by spark or flame
- Level of Congestion: congested
- Model Run: Gaussian
- Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
- Orange: LOC was never exceeded --- (3.5 psi = serious injury likely)
- Yellow: 68 yards --- (1.0 psi = shatters glass)


Overpressure (Blast Force) Threat Zone
yards
30
10
0
10
30
20
0
20
40
60
80
yards
wind
greater than 8.0 psi (destruction of buildings)
greater than 3.5 psi (serious injury likely)
greater than 1.0 psi (shatters glass)
wind direction confidence lines

5. Consequence analysis: Leakage on GVU-ME pipe

CHEMICAL DATA:

- Chemical Name: METHANE
- CAS Number: 74-82-8
- Molecular Weight: 16.04 g/mol
- PAC-1: 65000 ppm
- PAC-2: 230000 ppm
- PAC-3: 400000 ppm
- LEL: 50000 ppm
- UEL: 150000 ppm
- Ambient Boiling Point: -258.7° F
- Vapor Pressure at Ambient Temperature: greater than 1 atm
- Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)

- Wind: 20 miles/hour from nnw at 3 meters
- Ground Roughness: open water
- Cloud Cover: 0 tenths
- Air Temperature: 16° C
- Stability Class: E
- No Inversion Height
- Relative Humidity: 75%

SOURCE STRENGTH:

- Flammable gas escaping from pipe (not burning)
- Pipe Diameter: 11.43 centimeters Pipe Length: 23 meters
- Unbroken end of the pipe is connected to an infinite source
- Pipe Roughness: smooth
- Hole Area: 103 sq cm

- Pipe Press: 472000 pascals
- Pipe Temperature: 0° C
- Release Duration: ALOHA limited the duration to 1 hour
- Max Average Sustained Release Rate: 606 pounds/min (averaged over a minute or more)
- Total Amount Released: 36,361 pounds

THREAT ZONE:

- Model Run: Gaussian
- Red : 20 yards --- (400000 ppm = PAC-3)
- Orange: 26 yards --- (230000 ppm = PAC-2)
- Yellow: 50 yards --- (65000 ppm = PAC-1)

  Note: Threat zone was not drawn because effects of near-field patchiness make dispersion predictions less reliable for short distances.

STUDY TITLE: Process on Pressure Build up Evaporator (PBE)											SHEET: 1 of 2	
Drawing No.: PBU-1			REV. No.:								DATE: 25 April 2016	
PART CONSIDERED:			Transfer and evaporate LNG to increase tank pressure									
DESIGN INTENT: Min. 5 Max. 20 (Pressure, bar)			Material: LNG Source: LNG Tank				Activity: Transfer and Evaporate Destination: LNG Tank					
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required	
1	NO	LNG Transfer	No LNG transfer to tank	Failure on SAV-04 Valve, fail to open	2.62×10^{-3}	3	Operation of dual fuel system will be delayed	4	Pressure transmitter P-01	12	Yes	
2	LESS	LNG Transfer	Less LNG transfer to tank	Leakage	9.27×10^{-5}	2	Operation will be degraded because not enough pressure to transfering LNG to GVU and excessive pressure on cool box could generate explosion	5	Pressure transmitter P-01 and exchange fan	10	No	
3	MORE	LNG Transfer	More LNG transfer to tank	Failure on SAV-04 valve, fail to close	2.63×10^{-3}	3	Excessive flow to the tank will increase tank pressure, if the pressure in tha tank more than 20 bar could inflict explosion	5	Pressure transmitter P-01	15	Yes	
4	NO	LNG Evaporate	Cannot evaporate LNG	Failure on evaporate system	2.6×10^{-3}	3	Operation will be delayed because not enough pressure to transfering LNG to GVU	4	Flow meter on evaporator system	12	Yes	

STUDY TITLE: Process on Pressure Build up Evaporator (PBE)											SHEET: 2 of 2	
Drawing No.: PBU-1			REV. No.:								DATE: 25 April 2016	
PART CONSIDERED:			Transfer and evaporate LNG to increase tank pressure									
DESIGN INTENT: Min. 5 Max. 20 (Pressure, bar)			Material: LNG Source: LNG Tank				Activity: Transfer and Evaporate Destination: LNG Tank					
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required	
5	LESS	LNG Vapor	Less LNG vapor which will be transferred to the tank	Leakage	9.27×10^{-5}	2	Operation will be degraded because not enough pressure to transfering LNG to GVU and excessive pressure on cool box could generate explosion	5	Pressure transmitter P-01 and exchange fan	10	No	
6	MORE	LNG Vapor	More LNG vapor which will be transferred to the tank	Fail to monitor pressure on the tank	2.6×10^{-3}	3	Excessive pressure on the tank and very potential to be an explosion	5	Pressure transmitter P-01	15	Yes	
				Failure on SAV-05 valve, fail to close	2.65×10^{-3}	3	Excessive pressure on the tank and very potential to be an explosion	5	Pressure transmitter P-01	15	Yes	

STUDY TITLE: Process on Cool Box											SHEET: 1 of 2	
Drawing No.: PBU-1			REV. No.:								DATE: 25 April 2016	
PART CONSIDERED:			Transfer and evaporate LNG to GVU									
DESIGN INTENT: Min. 5			Material: LNG				Activity: Transfer and Evaporate					
Max. 10 (Pressure, bar)			Source: LNG Tank				Destination: GVU					
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Seveity level	Safeguards	Risk level	Action required	
1	NO	LNG Flow	Cannot transfering LNG from LNG tank to GVU	Failure on SAV-06 valve, fail to open	2.09×10^{-5}	2	Operation of dual fuel system will be delayed	4	Pressure transmitter P-02	8	No	
				Failure on SAV-07 valve, fail to close	2.09×10^{-5}	2	Operation of dual fuel system will be delayed	4	Pressure transmitter P-02	8	No	
2	LESS	LNG Flow	Less LNG flow from LNG tank to GVU	Leakage	7.5×10^{-5}	2	Operation of dual fuel system will be degraded	3	Pressure transmitter P-04 and exchange fan	6	No	
3	MORE	LNG Flow	More LNG flow from LNG tank to GVU	Failure on SAV-07 valve, fail to close	2.56×10^{-5}	2	Operation of dual fuel system will be degraded	3	Pressure transmitter P-02	6	No	
4	NO	LNG Evaporator	Cannot evaporating LNG	Failure on evaporate system	2.6×10^{-3}	3	Operating of dual fuel system will be delayed	4	Pressure transmitter P-03 and evaporator E-01	12	Yes	
5	LESS	LNG Vapor	Less LNG vapor which transferred from LNG tank to GVU	Leakage	7.5×10^{-5}	2	Not enough pressure to operate dual fuel system and will be degraded engine performance	3	Pressure transmitter P-04 and exchange fan	6	No	

STUDY TITLE: Process on Cool Box											SHEET: 2 of 2	
Drawing No.: PBU-1			REV. No.:								DATE: 25 April 2016	
PART CONSIDERED:			Transfer and evaporate LNG to GVU									
DESIGN INTENT: Min. 5 Max. 10 (Pressure, bar)			Material: LNG				Activity: Transfer and Evaporate					
			Source: LNG Tank				Destination: GVU					
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Seveity level	Safeguards	Risk level	Action required	
6	MORE	LNG Vapor	More LNG vapor which transferred from LNG tank to GVU	Failure on SAV-07 valve, fail to close	2.56×10^{-5}	2	Excessive gas flow from LNG tank and degraded performance on main engine (Knocking)	3	Pressure transmitter P-04 and actuator valve SAV-05	6	No	
				Failure on pressure transmitter	6.55×10^{-6}	1	Degraded performance on main engine (Knocking)	3	Pressure transmitter P-04 and actuator valve SAV-05	3	No	

STUDY TITLE: Process on Heat Exchanger (auxiliary system)									SHEET: 1 of 1	
Drawing No.: AXME-1			REV. No.:						DATE: 26 April 2016	
PART CONSIDERED:			Heat exchange from evaporator (PBE-01) and transferring to evaporate (MGE-01)							
DESIGN INTENT: Min. 5^o			Material: Glycol Water			Activity: THEat exchange and transfer				
Max. 30^o (Temperature,			Source: PBE-01			Destination: MGE-01				
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Seveity level	Safeguards	Risk level	Action required
1	NO	Glycol Water Transfer	No glycol water transfer from PBE-01 to MGE-01	Failure on pump	2.6×10^{-3}	3	Operation of dual fuel system will be delayed	4	Flow meter and emergency power supply	12	Yes
				Fail to regulate valve	1×10^{-6}	1	Operation of dual fuel system will be delayed for a while	3	Flow meter and emergency power supply	3	No
2	LESS	Glycol Water Transfer	Less Glycol water which transferred from PBE-01 to MGE-01	Leakage	1.11×10^{-6}	1	Degraded operation of dual fuel system	3	Flow meter FMHE-01/FMHE-02	3	No
3	MORE	Glycol Water Temperature	More glycol water temperature to MGE-01	Failure on temperature sensors	9.34×10^{-6}	1	Excessive LNG vapor that flow to GVU and could degraded engine performance	3	Flow meter FMHE-01/FMHE-02	3	No

STUDY TITLE: Process on Heat Exchanger (auxiliary system)									SHEET: 1 of 1	
Drawing No.: AXME-1			REV. No.:						DATE: 26 April 2016	
PART CONSIDERED:			Heat exchange from evaporator (E-01) and transferring to evaporate (E-01)							
DESIGN INTENT: Min. 5^{o}			Material: Glycol Water			Activity: Heat exchange and transfering				
Max. 30^{o} (Temperature,			Source: E-01			Destination: E-01				
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required
1	NO	Glycol Water Transfer	No glycol water transfer from E-01 to E-01	Failure on pump	2.6×10^{-3}	3	Operation of dual fuel system will be dalayed	4	Flow meter and emergency power supply	12	Yes
				Fail to regulate valve	1×10^{-6}	1	Operation of dual fuel system will be dalayed fro a while	3	Flow meter and emergency power supply	3	No
2	LESS	Glycol Water Transfer	Less glycol water which transferd from E-01 to E-01	Leakage	1.11×10^{-6}	1	Degraded opration of dual fuel system	3	Flow meter FMHE-03/FMHE-04	3	No
3	MORE	Glycol Water Temperature	More glycol water temperature to MGE-01	Failure on temperature sensors	9.34×10^{-6}	1	The pressure which going to GVU will be exceed from the normal operation	3	Flow meter FMHE-03/FMHE-04	3	No

STUDY TITLE: Process on Gas Valve Unit to transfer LNG Vapor										SHEET: 1 of 2	
Drawing No.: GVU-1			REV. No.:							DATE: 27 April 2016	
PART CONSIDERED:			Transfer and controlling LNG vapor								
DESIGN INTENT: Min. 5 Max. 10 (Pressure, bar)			Material: LNG Vapor Source: LNG Tank (Cool Box)				Activity: Transfering and controlling Destination: Engine				
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required
1	NO	LNG Vapor Transfer	No LNG vapor transfer	Failure on VSO-01 valve, fail to open	2.09×10^{-5}	2	Operating of dual fuel system will be deayed	4	Pressure transmitter P-02	8	No
				Failure VB-01 and VB-02 valve, fail to open	2.6×10^{-3}	3	Operating of dual fuel system will be deayed and excessive pressure on GVU room could generate an explosion	5	Pressure transmitter P-01 and P-02	15	Yes
				Failure on VG-01 valve, fail to open	2.6×10^{-3}	3	Operating of dual fuel system will be deayed	4	Pressure transmitter P-04	12	Yes
2	LESS	LNG Vapor Transfer	Less LNG vapor transfer	Leakage	3.8×10^{-3}	3	Operating of dual fuel system will be degraded	2	Pressure transmitter P-04 and P-07	6	No
				Failure on VG-01 valve, fail to regulate valve	1.01×10^{-5}	2	Operating of dual fuel system will be degraded	3	Pressure transmitter P-04	6	No
3	MORE	LNG Vapor Transfer	More LNG vapor transfer	Failure on VSO-01 valve, fail to close	3.09×10^{-5}	2	Operating of dual fuel system will be degraded	3	Pressure transmitter P-02	6	No

STUDY TITLE: Process on Gas Valve Unit to transfer LNG Vapor											SHEET: 2 of 2	
Drawing No.: GVU-1			REV. No.:								DATE: 27 April 2016	
PART CONSIDERED:			Transfer and controlling LNG vapor									
DESIGN INTENT: Min. 5 Max. 10 (Pressure, bar)			Material: LNG Vapor				Activity: Transfering and controlling					
			Source: LNG Tank (Cool Box)				Destination: Engine					
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required	
				Failure on VG-01 valve, fail to close	2.6×10^{-3}	3	Operating of dual fuel system will be degraded	3	Pressure transmitter P-04	9	Yes	
4	LESS	LNG Vapor Pressure	Less LNG vapor pressure	Leakage	3.8×10^{-3}	3	Operating of dual fuel system will be degraded	3	Pressure transmitter P-04 and P-07	9	Yes	
5	MORE	LNG Vapor Pressure	More LNG vapor pressure	Failure on VG-01 Valve, fail to close	2.6×10^{-3}	3	Degrading engine performance. Could generate pipe leaks or explosion if pressure more than 16 bar	3	Pressure transmitter P-04	9	Yes	
				Failure on pressure transmitter	6.55×10^{-6}	1	Cannot detect if there any over pressure and could generate explosion on GVU	5	None shown	5	No	

STUDY TITLE: Emergency stop of GVU and purging gas distribution										SHEET: 1 of 1	
Drawing No.: GVU-1			REV. No.:							DATE: 29 April 2016	
PART CONSIDERED:			Emergency stop and purging gas distribution on GVU								
DESIGN INTENT: Min. 5 Max. 15 (Pressure, bar)			Material: Inert Gas					Activity: Emergency Stop and Purging			
			Source: Inert Gas System					Destination: GVU			
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required
1	NO	Inert Gas	No inert gas flow when emergency	Failure on VSO-02 Valve, fail to open	2.09×10^{-5}	2	Delay operation of dual fuel engine	4	Pressure transmitter P-05	8	No
2	LESS	Inert Gas	Less inert gas flow when emergency	Leakage	3.8×10^{-3}	3	Degraded operation on gas inert system	2	Pressure transmitter P-05 and P-07	6	No
3	MORE	LNG Vapor	There are still LNG vapor on GVU when emergency condition	Failure on VSO-01 Valve, fail to close	2.57×10^{-5}	2	Excessive pressure on GVU pipe and could inflict explosion	5	Gas control valve VG-01 and pressure transmitter P-04	10	Yes
				Failure on VV-01 or VV-02 valve, fail to open	2.6×10^{-3}	3	LNG vapor trap on GVU system and will be delayed dual fuel operation	4	Gas control valve VG-01 and pressure transmitter P-04	12	Yes

STUDY TITLE: Internal Fuel Gas System										SHEET: 1 of 1	
Drawing No.: FGS-1			REV. No.:							DATE: 29 April 2016	
PART CONSIDERED:			Transfering LNG Vapor from GVU to Engine Cylinder								
DESIGN INTENT: Min. 5			Material: LNG Vapor					Activity: Transfering and Controlling			
Max. 10 (Pressure, bar)			Source: GVU					Destination: Engine Cylinder			
No.	Guide Word	Element	Deviation	Possible causes	Probability failure	Probability level	Consequences	Severity level	Safeguards	Risk level	Action required
1	NO	LNG Vapor	There are no LNG vapor flow to engine cylinder	Failure on gas admision valve	4.68×10^{-2}	4	Dual fuel operating will be delayed	4	None shown	16	Yes
2	LESS	LNG Vapor	Less amount of LNG vapor that going to cylinder	Leakage	3.8×10^{-3}	3	Operating of dual fuel system will be degraded	3	Vent valve	9	Yes
				Failure on gas admision valve	4.68×10^{-2}	4	Operating of dual fuel system will be degraded	3	None shown	12	Yes
3	MORE	LNG Vapor Pressure	Excessive pressure on LNG vapor which going to cylnder	Failure on gas admision valve	1.18×10^{-1}	5	Operating of dual fuel system will be degraded, engine knocking	3	None shown	15	Yes

MITIGATION
LOPA WORKSHEET

Scenario No. 1	No LNG transfer to tank caused by failure on SAV-04 Valve, fail to open		Node No. 1
Date: 20 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operation of dual fuel system will be delayed/ 4		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on SAV-04 Valve, fail to open		2.62×10^{-3}
Frequency of Unmitigated Consequence			2.62×10^{-3}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	Low pressure alarm	5.01×10^{-3}	
Total PFD		3.28×10^{-8}	
Frequency of Mitigated Consequence			8.59×10^{-11}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. Low pressure alarm should be installed		

Scenario No. 2	More LNG transfer to tank caused by failure on SAV-04 valve, fail to close		Node No. 1
Date: 20 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Excessive flow to the tank will increase tank pressure, if the pressure in tha tank more than 20 bar could inflict explosion/ 5		
Risk Tolerance Criteria	Action required		$>10^{-5}$
	Tolerable		$<10^{-5}$
Initiating event	Failure on SAV-04 valve, fail to close		2.63×10^{-3}
Frequency of Unmitigated Consequence			2.63×10^{-3}
Independent Protection Layers	Pressure safety valve	1.93×10^{-6}	
	Gas detector	5.66×10^{-6}	
	Exchange fan	5.39×10^{-3}	
Total PFD		5.88×10^{-14}	
Frequency of Mitigated Consequence			1.54×10^{-16}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure safety valve		
	2. Gas detector should be installed independent		
	3. There are should be exchange fan for each cool box		

Scenario No. 3	Cannot evaporate LNG caused by failure on evaporate system		Node No. 1
Date: 20 June 2016	Description	Probability	Frequency (per year)
Consequence description/ Category	Operation will be delayed because not enough pressure to transfering LNG to GVU/ 4		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on evaporate system		2.62×10^{-3}
Frequency of Unmitigated Consequence			2.62×10^{-3}
Independent Protection Layers	Flow sensor	4.4×10^{-6}	
	Pressure transmitter	6.55×10^{-6}	
	Low pressure alarm	5.01×10^{-3}	
Total PFD		1.44×10^{-13}	
Frequency of Mitigated Consequence			3.78×10^{-16}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with flow sensor		
	2. System need to be installed with pressure transmitter		
	3. Low pressure alarm should be installed		

Scenario No. 4	More LNG vapor which will be transferred to the tank caused by fail to monitor pressure on the tank		Node No. 1
Date: 20 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Excessive pressure on the tank and very potential to be an explosion/ 5		
Risk Tolerance Criteria	Action required		$>10^{-5}$
	Tolerable		$<10^{-5}$
Initiating event	Fail to monitor pressure on the tank		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Pressure safety valve	1.93×10^{-6}	
	Gas detector	5.66×10^{-6}	
	Exchange fan	5.39×10^{-3}	
Total PFD		5.88×10^{-14}	
Frequency of Mitigated Consequence			1.53×10^{-16}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure safety valve		
	2. Gas detector should be installed independent		
	3. There are should be exchange fan for each cool box		

Scenario No. 5	More LNG vapor which will be transferred to the tank caused by failure on SAV-05 valve, fail to close		Node No. 1
Date: 20 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Excessive pressure on the tank and very potential to be an explosion/ 5		
Risk Tolerance Criteria	Action required		$>10^{-5}$
	Tolerable		$<10^{-5}$
Initiating event	Failure on SAV-05 valve, fail to close		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Pressure safety valve	1.93×10^{-6}	
	Gas detector	5.66×10^{-6}	
	Exchange fan	5.39×10^{-3}	
Total PFD		5.88×10^{-14}	
Frequency of Mitigated Consequence			1.53×10^{-16}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure safety valve		
	2. Gas detector should be installed independent		
	3. There are should be exchange fan for each cool box		

Scenario No. 1	No LNG transfer to tank caused by failure on SAV-04 Valve, fail to open		Node No. 2
Date: 20 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operation of dual fuel system will be delayed/ 4		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on SAV-04 Valve, fail to open		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Flow sensor	4.4×10^{-6}	
	Pressure transmitter	6.55×10^{-6}	
	Low pressure alarm	5.01×10^{-3}	
Total PFD		1.44×10^{-13}	
Frequency of Mitigated Consequence			3.74×10^{-16}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with flow sensor		
	2. System need to be installed with pressure transmitter		
	3. Low pressure alarm should be installed		

Scenario No. 1	No glycol water transfer from PBE-01 to MGE-01 caused by failure on pump		Node No. 3
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operation of dual fuel system will be delayed/ 4		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on pump		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Flow sensor	4.4×10^{-6}	
	Emergency genset	5.94×10^{-3}	
	Low pressure alarm	5.01×10^{-3}	
Total PFD		1.44×10^{-13}	
Frequency of Mitigated Consequence			1.3×10^{-10}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with flow sensor		
	2.The power for pumps are need to be supplyed by emergency electric generator		
	3. Low pressure alarm should be installed		

Scenario No. 1	No glycol water transfer from PBE-01 to MGE-01 caused by failure on pump		Node No. 4
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operation of dual fuel system will be delayed/ 4		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on pump		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Flow sensor	4.4×10^{-6}	
	Emergency genset	5.94×10^{-3}	
	Low pressure alarm	5.01×10^{-3}	
Total PFD		1.44×10^{-13}	
Frequency of Mitigated Consequence			1.3×10^{-10}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with flow sensor		
	2.The power for pumps are need to be supplyed by emergency electric generator		
	3. Low pressure alarm should be installed		

Scenario No. 1	No LNG vapor transfer caused by failure VB-01 and VB-02 valve, fail to open		Node No. 5
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operating of dual fuel system will be deayed and excessive pressure on GVU room could generate an explosion/ 5		
Risk Tolerance Criteria	Action required		$>10^{-5}$
	Tolerable		$<10^{-5}$
Initiating event	Failure VB-01 and VB-02 valve, fail to open		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	High pressure alarm	3.13×10^{-3}	
	Pressure safety valve	1.93×10^{-6}	
Total PFD		3.95×10^{-14}	
Frequency of Mitigated Consequence			1.027×10^{-16}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. High pressure alarm should be installed		
	1. System need to be installed with pressure safety valve		

Scenario No. 2	No LNG vapor transfer caused by failure on VG-01 valve, fail to open		Node No. 5
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operating of dual fuel system will be deayed/ 4		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on VG-01 valve, fail to open		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	High pressure alarm	3.13×10^{-3}	
	Pressure safety valve	1.93×10^{-6}	
Total PFD		3.95×10^{-14}	
Frequency of Mitigated Consequence			1.027×10^{-16}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. High pressure alarm should be installed		
	3. System need to be installed with pressure safety valve		

Scenario No. 3	More LNG vapor transfer caused by failure on VG-01 valve, fail to close		Node No. 5
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operating of dual fuel system will be degraded/ 3		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on VG-01 valve, fail to close		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	High pressure alarm	3.13×10^{-3}	
	Pressure safety valve	1.93×10^{-6}	
Total PFD		3.95×10^{-14}	
Frequency of Mitigated Consequence			1.027×10^{-16}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. High pressure alarm should be installed		
	3. System need to be installed with pressure safety valve		

Scenario No. 4	Less LNG vapor pressure caused by leakage		Node No. 5
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operating of dual fuel system will be degraded/ 3		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Leakage		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	Gas detector	5.66×10^{-6}	
	Exchange fan	5.39×10^{-3}	
Total PFD		1.99×10^{-13}	
Frequency of Mitigated Consequence			7.56×10^{-16}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. Gas detector should be installed independent		
	3. There are should be exchange fan for each cool box		

Scenario No. 5	More LNG vapor pressure caused by failure on VG-01 Valve, fail to close		Node No. 5
Date: 21 June 2016	Description	Probability	Frequency (per year)
Consequence description/ Category	Degrading engine performance. Could generate pipe leaks or explosion if pressure more than 16 bar/ 3		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on VG-01 Valve, fail to close		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	Pressure safety valve	1.93×10^{-6}	
	Gas detector	5.66×10^{-6}	
	Exchange fan	5.39×10^{-3}	
Total PFD		1.99×10^{-13}	
Frequency of Mitigated Consequence			1.46×10^{-21}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. System need to be installed with pressure safety valve		
	3. Gas detector should be installed independent		
	4. There are should be exchange fan for each cool box		

Scenario No. 1	There are still LNG vapor on GVU when emergency condition caused by failure on VSO-01 Valve, fail to close		Node No. 6
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Excessive pressure on GVU pipe and could inflict explosion/ 5		
Risk Tolerance Criteria	Action required		$>10^{-5}$
	Tolerable		$<10^{-5}$
Initiating event	Failure on VSO-01 Valve, fail to close		2.57×10^{-5}
Frequency of Unmitigated Consequence			2.57×10^{-5}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	Pressure safety valve	1.93×10^{-6}	
	Gas detector	5.66×10^{-6}	
	Exchange fan	5.39×10^{-3}	
Total PFD		1.99×10^{-13}	
Frequency of Mitigated Consequence			5.1×10^{-18}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. System need to be installed with pressure safety valve		
	3. Gas detector should be installed independent		
	4. There are should be exchange fan for each cool box		

Scenario No. 2	There are still LNG vapor on GVU when emergency condition caused by failure on VV-01 or VV-02 valve, fail to open		Node No. 6
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	LNG vapor trap on GVU system and will be delayed dual fuel operation/ 4		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on VV-01 or VV-02 valve, fail to open		2.6×10^{-3}
Frequency of Unmitigated Consequence			2.6×10^{-3}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	Pressure safety valve	1.93×10^{-6}	
	Gas detector	5.66×10^{-6}	
	Exchange fan	5.39×10^{-3}	
Total PFD		1.99×10^{-13}	
Frequency of Mitigated Consequence			1.46×10^{-21}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. System need to be installed with pressure safety valve		
	3. Gas detector should be installed independent		
	4. There are should be exchange fan for each cool box		

Scenario No. 1	There are no LNG vapor flow to engine cylinder caused by failure on gas admision valve		Node No. 7
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operating of dual fuel system will be deayed/ 4		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on gas admision valve		4.68×10^{-2}
Frequency of Unmitigated Consequence			4.68×10^{-2}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
	Low pressure alarm	5.01×10^{-3}	
Total PFD		3.28×10^{-8}	
Frequency of Mitigated Consequence			1.53×10^{-9}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		
	2. Low pressure alarm should be installed		

Scenario No. 2	Less amount of LNG vapor that going to cylinder caused by leakage		Node No. 7
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operating of dual fuel system will be degraded/ 3		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Leakage		3.8×10^{-3}
Frequency of Unmitigated Consequence			3.8×10^{-3}
Independent Protection Layers	Vent valve	2.52×10^{-5}	
	Gas detector	5.66×10^{-6}	
	Exchange fan	5.39×10^{-3}	
Total PFD		7.68×10^{-13}	
Frequency of Mitigated Consequence			2.92×10^{-15}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with vent valve		
	2. Gas detector should be installed independent		
	3. There are should be exchange fan for each cool box		

Scenario No. 3	Less amount of LNG vapor that going to cylinder caused by failure on gas admision valve		Node No. 7
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operating of dual fuel system will be degraded/ 3		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on gas admision valve		4.68×10^{-2}
Frequency of Unmitigated Consequence			4.68×10^{-2}
Independent Protection Layers	Pressure transmitter	6.55×10^{-6}	
Total PFD		6.55×10^{-6}	
Frequency of Mitigated Consequence			3.06×10^{-7}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. System need to be installed with pressure transmitter		

Scenario No. 4	Excessive pressure on LNG vapor which going to cylnder caused by failure on gas admision valve		Node No. 7
Date: 21 June 2016	**Description**	**Probability**	**Frequency (per year)**
Consequence description/ Category	Operating of dual fuel system will be degraded, engine knocking/ 3		
Risk Tolerance Criteria	Action required		$>10^{-4}$
	Tolerable		$<10^{-4}$
Initiating event	Failure on gas admision valve		1.18×10^{-1}
Frequency of Unmitigated Consequence			1.18×10^{-1}
Independent Protection Layers	High pressure alarm	3.13×10^{-3}	
	Pressure safety valve	1.93×10^{-6}	
	Gas detector	5.66×10^{-6}	
	Exchange fan	5.39×10^{-3}	
Total PFD		1.84×10^{-16}	
Frequency of Mitigated Consequence			2.17×10^{-17}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. High pressure alarm should be installed		
	2. System need to be installed with pressure safety valve		
	3. Gas detector should be installed independent		
	4. There are should be exchange fan for each cool box		

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CHAPTER V
CONCLUSION

Using a LNG as a fuel on ship has many benefit, such as in economic factor and environmental factor, but there are some points to be consider in terms of safety. Based on the result of risk assessment for dual fuel engine on ferry ship, concluded that:

1. From 41 failure mode scenarios there are 18 failure mode which has moderate risk level and 1 failure mode on high risk level, rest of failure mode scenario has low risk level. Risk which is on moderate risk level and high risk level are need to mitigate.

2. Several risk which generated in dual fuel system has a severity of LNG tank BLEVE, these risk had been mitigated using LOPA method by adding several items to reduce the value of frequency.

3. Highest risk level on those scenario is failure mode of "No flow of LNG vapor to engine cylinder caused by failure on gas admission valve". The mitigation for this scenario had reach the low risk level by adding pressure transmitter and low pressure alarm to prevent the consequence and reduce the frequency.

4. There are two option of LNG tank location on the, above or below the deck. Due to several reason, such as requires zoned and explosion consequence, location LNG tank above the deck more recommended than below the deck.

5. Ferry ship which is use a conventional diesel engine and want to modified their engine to dual fuel engine are need to install several items on the engine, such as dual needle injection valve, control unit, gas admission valve and gas rail pipe, and need adding Gas Valve Unit (GVU) for each engine and LNG tank.

6. Using a double pipe for gas fuel system very recommended to prevent gas leak.

7. GVU need to be located on enclosure area, different area with main engine. The GVU room must be fulfilled with independent gas detector and exchange fan for each room.

8. Independent gas detector required for each main engine, GVU and Cool Box.

9. There are two option on the Cool Box for transferring LNG from LNG tank to GVU which are by using pump or Pressure Build-up Evaporator (PBE). Using PBE more recommended than pump because of reliable and safety factor.

10. All items which need a power supply, such as solenoid valve, motor pump, motor fan, gas detector and alarm, must be connected to the emergency power supply.

11. Due to several risk with high consequence category, then the operational of dual fuel must always monitored, to support the monitoring activity a good and reliable items are needed. There for the activity of inspection and maintenance for those items are need to be done periodically.

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