Risk Based Design of LNG Regasification Terminal in Kupang

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Abstract. The government of Indonesia has decided to switch fossil fuel to LNG for power plant fuel supply. According to Indonesian Ministry of Energy and Mineral Resources Decree RI No. 13K/13/MEM/2020, the government of Indonesia has decided to switch fossil fuel to LNG for 52 power plants in Indonesia, PLTMG Kupang Peaker is one of them. Currently, there are no facilities for receiving and regasification LNG in Kupang. Therefore, this research will accommodate the design of LNG regasification terminal by utilizing the vacant land in PLTMG Kupang Peaker area. The design is based on NFPA 59A and evaluated through fire risk assessment. In this research, the fire risk assessment consists of identifying hazards with HAZOP studies according to BS IEC 61882:2001 standard, frequency analysis through fault tree analysis (FTA) and event tree analysis (ETA), consequences analysis using fire modelling software ALOHA, and risk mapping using f-N curve UK societal risk criteria for process facility. From the risk mapping, there are 4 scenarios that are in the intolerable region. After mitigation using Layer of Protection Analysis (LOPA), the frequency value decreases and the risk for 4 scenarios that previously in the intolerable region can be lowered to the acceptable region.

1. Introduction

Electricity consumption in Indonesia continues to increase every year in line with the increasing of economic growth and public access to electricity. In 2018, electricity consumption in Indonesia was 1,064 kWh per capita, which is higher than in 2017 and 2016. In 2017, the electricity consumption was 1,012 kWh per capita, while in 2016 was 956 kWh per capita [1]. For the future, the government of Indonesia already targeted in 2024 the electricity consumption to reach 1,408 kWh per capita [2]. With the increasing of electricity consumption in Indonesia, the demand of fuel for power plant is also increasing. Many power plant in Indonesia still use coal and petroleum products.

The government of Indonesia has decided to switch fossil fuel to LNG for power plant fuel supply. According to Indonesian Ministry of Energy and Mineral Resources Decree RI No. 13K/13/MEM/2020, PT Pertamina (Persero) is assigned to provide supply and development of LNG infrastructure. Meanwhile, PT PLN (Persero) will be assigned to carry out power plant gasification activities and purchase LNG from PT Pertamina (Persero). The whole process will be carried out for 2 years at 52 locations of PLTG / PLTGU / PLTMG, with a total capacity of 1,697 MW and volume of gas demand about 166.98 BBTUD [3]. Based on the decree, PLTMG Kupang Peaker would receive 2.9 BBTUD of natural gas [3].
Currently, there is no facilities for LNG regasification in Kupang. Therefore, this research will accommodate the design of LNG regasification terminal by utilizing the vacant land in PLTMG Kupang Peaker area. LNG transported using LNG ISO Tank with container ship from Benoa LNG Terminal to Port of Tenau, Kupang. The LNG ISO Tank stacked in Port of Tenau container yard and transported to PLTMG Kupang Peaker using trucks. The regasification process will be done in PLTMG Kupang Peaker area.

Compared to fossil fuel, natural gas resulting in fewer emissions [4]. Although natural gas is more environmentally friendly, it has high risk of fire and explosion. There are several accidents occurred involving LNG or natural gas, such as heat exchanger explosion in Bontang, Indonesia in 1983, A pipeline carrying natural gas from the Belgian port of Zeebrugge to northern France exploded resulting 23 fatalities in 2004, catastrophic failure followed by explosion on Plymouth-LNG Peak Shaving Plant in United States of America (USA) resulting 5 employees injured in 2014 [5]. Therefore, it’s extremely important to do fire risk assessment to the designed LNG regasification terminal.

D H Baskoro, AAB Dinariyana, and KB Artana performed risk assessment to determine the level of risk to the fatality of human life to the floating storage regasification unit (FSRU) in West Java. The risk assessment started with identifying hazard using Hazard and Operability (HAZOP) and followed by analyzing the frequency of gas release using the Fault Tree Analysis (FTA) and Event Tree Analysis (ETA). The consequences analysis conducted through fire modelling software. The gas release frequency and fatalities caused by the hazard are plotted to the f-N curve to know whether the risk is in the acceptable area or not. K G W Budiarta, D W Handani, and AAB Dinariyana also doing similar research regarding risk assessment to planned design of the LNG Terminal in a port area of Semarang, Central Java using FTA, ETA, fire modelling, and f-N Curve. Therefore, this risk assessment methods are proven to be applicable for LNG facilities fire risk assessment.

In this research, the design follows the rules in NFPA 59A and evaluated through fire risk assessment. The fire risk assessment consists of hazard identification, frequency analysis, consequences analysis, risk mapping, and risk mitigation. From the process flow diagram, the potential hazards are identified using HAZOP studies according to BS IEC 61882 : 2001 standard. After evaluating the design with HAZOP, based on the comment and recommendation, the previous design will be developed to the Piping & Instrumentation Diagram (P&ID). The frequency analysis done to the P&ID using two methods, namely FTA and ETA. Afterwards, the consequence analysis will be conducted using ALOHA fire modelling software to analyze the effect of fire hazard to the fatalities of LNG regasification terminal and PLTMG Kupang Peaker worker life. The frequency and consequence analysis that have been carried out will be plotted and represented using f-N curve UK Societal Risk criteria for a process facility to analyze the level of risk. If the level of risk from risk mapping is in intolerable region, risk mitigation will be done to the design. This research is only covering the design and risk assessment for the regasification process in PLTMG Kupang Peaker area. This research also not considering the economical aspect.

2. Methodology
The methodology used in this research explained briefly in this chapter.

2.1. LNG Regasification Terminal Equipment Specification
There is several equipment required for the process of turning LNG back to natural gas namely LNG Storage Tank, LNG Pump, LNG and natural gas pipe, boil off gas (BOG) treatment, and regasification unit. The minimum requirement of all equipment is calculated as the basis to determining and choosing the specification of the equipment.

2.2. LNG Regasification Terminal Process Flow Diagram (PFD)
Process flow diagram (PFD) is use to show the general flow of the LNG regasification terminal. PFD only include major equipment and exclude minor details such as instrumentations. The PFD of the LNG regasification terminal configuration will be designed using AutoCAD software.
2.3. **LNG Regasification Terminal Layout**

The LNG regasification terminal layout will be designed referring to NFPA 59A standard using AutoCAD software. The distance between component according to NFPA 59A can be seen in table 1.

| Criteria | Distance |
|----------|----------|
| Storage tank distance between storage tank | 1.5 m |
| Storage tank distance between storage tank and property >= 114 – 265 m³ | 23 m |
| Vaporizers Distance between vaporizers and property | 30 m |
| Distance between vaporizers and storage tank | 15 m |
| Distance between vaporizers and process equipment | 15 m |
| Distance between vaporizers and loading unloading connection | 15 m |
| Clearance between vaporizers | 1.5 m |
| Process Equipment (pump) distance between process equipment and property | 15 m |

2.4. **Hazard Identification**

Hazard identification will be conducted after the completion of process flow diagram and lay out of LNG regasification terminal. LNG regasification terminal system divided into several nodes as the initial step of HAZOP studies. The division of nodes is based on the function and complexity of the systems and the severity of hazards.

Through hazard identification, the cause and type of hazard can be determined. Hazard identification will be conducted with HAZOP according to BS IEC 61882: 2001 standard. In this standard, HAZOP worksheet consist of guideword, element, deviation, possible causes, consequences, safeguard, comment dan action required provided for hazard identification guidance.

2.5. **LNG Regasification Terminal Piping & Instrumentation Diagram (P&ID)**

Piping & Instrumentation Diagram (P&ID) is use to show the detailed diagram of the LNG regasification terminal including the piping, process equipment, instrumentation and control devices. After evaluating the design with HAZOP, based on the comment and recommendation, the previous design will be developed to the P&ID. The P&ID of the LNG regasification terminal configuration will be designed using AutoCAD software.

2.6. **Frequency Analysis**

The frequency analysis done to the P&ID using two methods, namely Fault Tree Analysis (FTA) and Event Tree Analysis (ETA). FTA is an analysis of the probability of the occurrences of the selected top event. The top event may occur via the combination of individual contributing failures (basic event). The top event in this research is gas release and the basic events are the leakage and failure of manual valves, actuated valves, process equipment pipes, Natural gas pipes to the pressure reduction and metering unit, pumps, and safeguards & instrumentation.

The leakage frequency is using formula from DNV Process Equipment Failure Frequency for pipe and equipment between LNG regasification terminal area and 10th Report of the European Gas Pipeline Incident Data Group Period 1970 – 2016 for natural gas pipe from LNG regasification terminal to pressure reduction & metering unit. The frequency of component failure is using data from Offshore & Onshore Reliability Data (OREDA).

ETA describes the possible hazard outcomes in terms of the sequence of events (successes or failures of safety functions) that follow an initiating event. The initiating event is the gas release probability
from FTA and the possible hazards are the hazard that has been identified using HAZOP studies. The probability of each possible hazard is taken from secondary data using data from The Center for Chemical Process Safety (CCPS).

2.7. Consequences Analysis
The consequence analysis will be conducted using ALOHA fire modelling software to analyze the effect of fire hazard to the fatalities of LNG regasification terminal and PLTMG Kupang Peaker worker life. The number of workers on LNG Regasification Terminal and pressure reduction and metering unit can be seen on the table 2.

Table 2. The amount of worker on LNG Regasification Terminal and pressure reduction and metering unit area

| Node | Receiver                              | Amount of Worker |
|------|---------------------------------------|------------------|
| 1    | Attached LNG ISO Tank                 | 2                |
| 2    | LNG Pumps                             | 1                |
| 3-4  | Ambient Air Vaporizers                | 2                |
|      | Stacked LNG ISO Tank                  | 2                |
|      | Control Center                        | 3                |
|      | Office                                | 4                |
| 5    | Pressure Reduction and Metering Unit  | 2                |
|      | Dual fuel engines                     | 3                |
|      | Radiator                              | 2                |

2.8. Risk Mapping
The frequency and consequence analysis that have been carried out will be plotted and represented using f-N curve to analyse LNG regasification terminal level of risk. In the f-N curve, the results of the frequency per year (f) are represented on the y-axis and the results of the number of fatalities (N) or known as a societal risk which is the impact of an event represented on the x-axis. In this research the f-N curve will be FN-curve UK Societal Risk criteria for a process facility as seen in figure 1.

Figure 1. Typical FN-curve UK Societal Risk criteria for a process facility [6].
In FN-curve UK Societal Risk criteria for a process facility, there are three regions of the level of risk, namely, acceptable, As low as reasonably practice (ALARP), and intolerable. If the risk is in acceptable region, the level of risk can be accepted and there is no need for risk mitigation. If the risk is in ALARP region, the risk can be tolerable if the risk mitigation is not practical or the improvement of the level of risk is extremely not proportional to the cost of risk mitigation [7]. Lastly, if the level of risk is in the intolerable region, the risk is not acceptable and risk mitigation is mandatory to lower the level of risk.

2.9. Risk Mitigation
If the level of risk from risk mapping is intolerable, risk mitigation is mandatory. Layer of Protection Analysis (LOPA) will be used to lower the frequency of the hazard.

3. Result and Discussion

3.1. LNG Regasification Terminal Equipment
There is several equipment required for the process of turning LNG back to natural gas namely LNG Storage Tank, LNG Pump, LNG and natural gas pipe, boil off gas (BOG) treatment, and regasification unit.

For the LNG storage tank, 20” LNG ISO Tank will be used to contain LNG. There are two ISO LNG Tank connected to the LNG pump at the same time, one of them is in stand-by mode. The empty ISO LNG Tank shall be changed with full ISO LNG Tank immediately to avoid the two tanks becoming empty at the same time.

For the regasification unit, this research uses ambient air vaporizer (AAV). AAV is more environmentally friendly and suitable for peak power plant and smaller terminal. For powering five 9730 kW dual fuel engine used in PLTMG Kupang Peaker, 19.4 m³ LNG/hour which is equal to 10998.74 Nm³/hour of natural gas is needed. Adding operation margin of 1% from the engine required, the requirement becomes 12098.6 Nm³/hour. The chosen Ambien Air Vaporizer can be seen in table 3.

| Table 3. Ambient Air Vaporizer Specification |
|---------------------------------------------|
| Ambient Air Vaporizer                      |
| Maker           | Thermafin Supergap |
| Model           | SG1500HF - DH       |
| Nominal Capacity| 3036 Nm³/hour       |
| Pressure        | 15 bar              |
| Outlet Temperature | 10 °C              |
| Derating time   | 8 hours             |
| Amount          | 4 + 1 (redundant)   |
| Total capacity  | 12144 Nm³/hour      |

As the operation time of PLTMG Kupang Peaker is 5 hours, therefore it’s not necessary to provide extra AAV for defrosting time. Hence, one extra AAV still provided for redundant purpose.

LNG transferred from LNG ISO tank to ambient air vaporizers via LNG pump and pipeline. The minimum internal diameter \((D_{\text{in}})\) of LNG pipe is calculated with the formula 1, where \(Q\) is LNG flowrate and \(v\) is the velocity of LNG. The minimum thickness of the pipe is following guidance from ASME B31.3.

\[
D_{\text{in}} = \sqrt[4]{\frac{Q \times 4}{\pi \times v}}
\] (1)
The LNG pipe is using stainless steel pipe ASTM A312 TP316 as one of the pipe materials recommended by ASME B31.3. From the calculations, NPS 2” schedule 5S and NPS 1” schedule 5S chosen as the main and branch LNG pipe, respectively. The LNG pumps chosen based on the required LNG flowrate and pump total head (H). The total head (H) can be calculated by the following formula 2, where \( h_z \) is the static head, \( h_p \) is the pressure head, \( h_l \) is the head losses, and \( h_v \) is the velocity head. The specification of LNG pump chosen can be seen in table 4.

\[
H = h_z + h_p + h_l + h_v
\]  

(2)

| LNG Pump Specification |
|-------------------------|
| **Maker**               | Vanzetti          |
| **Model**               | SGM 160          |
| **Power installed**     | 160 kW           |
| **Max allowable working pressure** | 30 bar |
| **Max head**            | 225 m            |
| **Max flow rate**       | 520 lpm          |
|                        | 31.20 m³/h       |

LNG pumped to the ambient air vaporizers (AAVs) for turning back LNG to natural gas form. Natural gas from the AAVs transferred to pressure reduction and metering unit in the power plant side through 2.3 km natural pipeline. The equations used in calculating the diameter of the main natural gas pipe is using weymouth equation that can be seen in formula 3 [8]. This equation is most suitable for gas flows in pipelines with diameter 15 inches (381 mm) or less, for pipeline segment length less than 20 miles (32 km), and for medium to high pressure, which is approximately 100 psia (6.9 bar) to 1000 psia (69 bar) [8].

\[
D_{in} = 2.667 \sqrt{\frac{Q_b \times P_b}{433.5 \times T_b \times E \times \left( \frac{P_1^2 - P_2^2}{G x L x T x Z} \right)^{0.5}}}
\]  

(3)

The calculation of minimum natural gas pipe thickness will be following guidance from ASME B31.8. The natural gas pipe is A53 Type SS Grade A as one of the pipe materials recommended by ASME B31.8. From formula 3 and calculation guidance from ASME B31.8, NPS 5” schedule 40, NPS 1 ¼” schedule 40, and NPS ¼” schedule 40 are chosen as the main, branch, and boil-off gas pipe, respectively.

As the heat from ambient temperature affect the tanks, the LNG inside the tank evaporate and generate boil-off gas (BOG). The BOG rate of LNG per day from the LNG ISO Tank is 0.25%/day. BOG will be treated to suit the minimum inlet temperature of dual fuel engine, which is 0 °C. Therefore, ambient air heater installed to the system. The specification of ambient air heater can be seen in table 5.
### Table 5. Ambient air heater specification

|                      | Ambient Air Heater |
|----------------------|--------------------|
| Maker               | Thermafin Supergap |
| Model               | SG5HF              |
| Nominal Capacity    | 12 Nm³/hour       |
| Pressure            | 6.9 bar            |
| derating time       | 8 hours            |
| Length              | 280 mm             |
| Width               | 560 mm             |
| Height              | 1520 mm            |
| Amount              | 1+1 (Redundant)    |

3.2. LNG Regasification Terminal Process Flow Diagram

The component in the process flow diagram (PFD) is using from the previous section. The PFD can be seen in figure 2.

![Figure 2. LNG regasification terminal process flow diagram and the division of nodes](image)

3.3. LNG Regasification Terminal Layout

The layout of LNG regasification Terminal shall comply to NFPA 59A. The LNG regasification terminal layout can be seen in figure 3 and 4.
3.4. Hazard Identification

As the initial step of hazard identification, the system is divided into 5 nodes based on the function and the severity of the hazard. Node 1 is the process of containing LNG in ISO LNG Tank and LNG unloading, node 2 is the process of LNG transfer to ambient air vaporizers, node 3 is the process of regasification of LNG back to natural gas, node 4 is the process of Boil Off Gas Treatment, node 5 is the process of transferring natural gas to pressure reduction and metering unit through pipes. The
division of nodes in the process flow diagram can be seen in figure 2.

Each node is analyzed for the possible deviation from the design intent with the help of HAZOP sheet provided by BS IEC 61882:2001. The results of HAZOP studies indicated that the potential fire hazard that occurs LNG regasification terminal are gas release that can lead to fire. Afterwards, based on the comment and recommendation in HAZOP sheets, additional safeguards will be added to the previous design resulting P&ID as in figure 5, figure 6, and figure 7.

![Figure 5. P&ID for LNG ISO tank and unloading pipeline](image)

![Figure 6. P&ID for LNG Pumps and Ambient Air Vaporizers](image)
3.5. Frequency Analysis

The frequency analysis used the combination of two methods, Fault Tree Analysis (FTA) followed by Event Tree Analysis (ETA). The frequency analysis is done to the P&ID in figures 5, 6, and 7. The leakage scenario used 5 holes size diameter scenario, which are 10 mm, 25 mm, 50 mm, 100 mm, and 125 mm. The calculation of the frequency of leaks is done in the pre-determined scenario. The alternative scenario consists of full leaks, zero pressure leaks, and total leaks. In this research, all the leakage frequency is use total leak scenario, as total leak scenario can represent all the scenario possibilities.

Based on the result of HAZOP studies, fire hazard caused by gas release incident. Therefore, the top event used in FTA is gas release and the basic event is the leakage and failure of several components e.g., manual valves, actuated valves, pipes, pumps. The formula of the frequency of leaks is based on DNV Process Equipment Failure Frequencies and values from 10th Report of the European Gas Pipeline Incident Data Group Period 1970 – 2016. The value of all equipment failure is using data from Offshore Reliability Data Handbook (OREDA) : 2002. FTA structure of node 2 with hole diameter of 25 mm can be seen in figure 5. The recapitulation of FTA can be seen in table 6.

![Figure 7. P&ID for Boil Off Gas Heater & Pressure Reduction and Metering Unit](image)

![Figure 8. FTA Structure for Node 2 with 25 mm hole diameter configuration](image)
Table 6. FTA recapitulation for all nodes and hole diameter configurations

| Node | 10 mm | 25 mm | 50 mm | 100 mm | 150 mm |
|------|-------|-------|-------|--------|--------|
| 1    | 5.03E-03 | 9.11E-04 | 5.74E-04 | Not Applicable | Not Applicable |
| 2    | 4.92E-03 | 2.37E-03 | 1.40E-03 | Not Applicable | Not Applicable |
| 3    | 9.40E-03 | 4.81E-03 | 2.64E-04 | 1.66E-04 | 1.50E-04 |
| 4    | 1.93E-02 | Not Applicable | Not Applicable | Not Applicable | Not Applicable |
| 5    | 1.71E-03 | 6.90E-04 | 5.06E-04 | 2.22E-04 | 2.88E-04 |

Event tree analysis (ETA) used to determine the frequency of a possible hazard that follows initiating event (gas release) on every node. The initiating event for ETA is the gas release probability from FTA and the possible hazards configuration are jet fire, flash fire, and gas dispersion. The probability of each possible hazard is taken from secondary data using data from The Center for Chemical Process Safety (CCPS). ETA structure of node 2 with hole diameter of 25 mm can be seen in figure 9.

Figure 9. ETA Structure for Node 2 with 25 mm hole diameter configuration

3.6. Consequences Analysis
The consequences analysis conducted using fire modelling software ALOHA. The scenario to be analysed for the consequences analysis is jet fire and flash fire. Gas dispersion is not analyzed because natural gas is non-toxic and not harmful for human safety. Jet fire scenario for node 2 with 50 mm hole diameter configuration can be seen in figure 10.
Figure 10. Jet fire scenario for node 2 with 50 mm hole diameter configuration plotted to layout

3.7. Risk Mapping
The result of frequency and consequences analysis are plotted to the f-N Curve as a form of risk mapping. From the risk mapping, the level of risk of the system can be determined. The f-N Curve for flash fire node 4 with 10 mm hole diameter configuration can be seen in figure 11. The recapitulation of the results of the risk mapping of jet fire and flash fire scenario can be seen in the table 7 and 8, respectively.

Table 7. The recapitulation of risk mapping result of jet fire scenario

| NODE | Leak Scenario | Frequency | Fatalities | Acceptable | ALARP | Intolerable |
|------|---------------|-----------|------------|------------|-------|-------------|
| 1    | 10 mm         | 5.03E-04  | 5          | YES        |       |             |
|      | 25 mm         | 9.11E-05  | 5          | YES        |       |             |
|      | 50 mm         | 5.74E-05  | 7          | YES        |       |             |
|      | 100 mm        | Not Applicable | Not Applicable | Not Applicable |       |             |
|      | 125 mm        | Not Applicable | Not Applicable | Not Applicable |       |             |
| 2    | 10 mm         | 4.92E-04  | 1          | YES        |       |             |
|      | 25 mm         | 2.37E-04  | 3          | YES        |       |             |
|      | 50 mm         | 1.40E-04  | 7          | YES        |       |             |
|      | 100 mm        | Not Applicable | Not Applicable | Not Applicable |       |             |
|      | 125 mm        | Not Applicable | Not Applicable | Not Applicable |       |             |
| NODE | Leak Scenario | JET FIRE Frequency | Fatalities | Acceptable | ALARP | Intolerable |
|------|---------------|--------------------|------------|------------|--------|-------------|
| 3    | 10 mm         | 9.40E-04           | 2          | YES        |        |             |
|      | 25 mm         | 4.81E-04           | 2          | YES        |        |             |
|      | 50 mm         | 2.64E-05           | 2          | YES        |        |             |
|      | 100 mm        | 1.66E-05           | 2          | YES        |        |             |
|      | 125 mm        | 1.49E-05           | 2          | YES        |        |             |
| 4    | 10 mm         | 1.95E-03           | 2          | YES        |        |             |
|      | 25 mm         | Not Applicable     | Not Applicable | Not Applicable |     |             |
|      | 50 mm         | Not Applicable     | Not Applicable | Not Applicable |     |             |
|      | 100 mm        | Not Applicable     | Not Applicable | Not Applicable |     |             |
|      | 125 mm        | Not Applicable     | Not Applicable | Not Applicable |     |             |
| 5    | 10 mm         | 1.86E-04           | 2          | YES        |        |             |
|      | 25 mm         | 6.14E-05           | 2          | YES        |        |             |
|      | 50 mm         | 4.01E-05           | 5          | YES        |        |             |
|      | 100 mm        | 1.17E-05           | 5          | YES        |        |             |
|      | 125 mm        | 7.38E-06           | 5          | YES        |        |             |

Table 8. The recapitulation of risk mapping result of flash fire scenario

| NODE | Leak Scenario | FLASH FIRE Frequency | Fatalities | Acceptable | ALARP | Intolerable |
|------|---------------|----------------------|------------|------------|--------|-------------|
| 1    | 10 mm         | 3.40E-03             | 4          |            |        | YES         |
|      | 25 mm         | 6.15E-04             | 6          | YES        |        |             |
|      | 50 mm         | 3.88E-04             | 9          | YES        |        |             |
|      | 100 mm        | Not Applicable       | Not Applicable | Not Applicable |     |             |
|      | 125 mm        | Not Applicable       | Not Applicable | Not Applicable |     |             |
| 2    | 10 mm         | 3.32E-03             | 3          | YES        |        |             |
|      | 25 mm         | 1.60E-03             | 5          | YES        |        |             |
|      | 50 mm         | 9.45E-04             | 5          | YES        |        |             |
|      | 100 mm        | Not Applicable       | Not Applicable | Not Applicable |     |             |
|      | 125 mm        | Not Applicable       | Not Applicable | Not Applicable |     |             |
| 3    | 10 mm         | 6.35E-03             | 2          | YES        |        |             |
|      | 25 mm         | 3.25E-03             | 2          | YES        |        |             |
|      | 50 mm         | 1.78E-04             | 2          | YES        |        |             |
|      | 100 mm        | 1.12E-04             | 2          | YES        |        |             |
|      | 125 mm        | 1.01E-04             | 2          | YES        |        |             |
| 4    | 10 mm         | 1.32E-02             | 2          | YES        |        |             |
|      | 25 mm         | Not Applicable       | Not Applicable | Not Applicable |     |             |
|      | 50 mm         | Not Applicable       | Not Applicable | Not Applicable |     |             |
|      | 100 mm        | Not Applicable       | Not Applicable | Not Applicable |     |             |
|      | 125 mm        | Not Applicable       | Not Applicable | Not Applicable |     |             |
As seen in table 8, there are 4 scenarios that the level of risk is in the intolerable region that needed risk mitigation, which are flash fire node 1 with hole diameter scenario 10 mm, flash fire node 2 with hole diameter scenario 10 mm, flash fire node 3 with hole diameter scenario 10 mm, flash fire node 4 with hole diameter scenario 10 mm.

3.8. Risk Mitigation
The previous 4 scenarios are in intolerable region, therefore mitigation is mandatory. By using the Layer of Protection Analysis (LOPA) method, the frequency of hazards and risks can be evaluated as well as provide protection from risks that are intolerable.

For the mitigation, additional gas detectors, pressure alarms, and temperature alarms are added to node 1, node 2, node 3, and node 4. LOPA worksheet for flash fire node 2 hole diameter 10 mm scenario can be seen in table 9.

| NODE | Leak Scenario | Frequency | Fatalities | Acceptable | ALARP | Intolerable |
|------|---------------|-----------|------------|------------|-------|-------------|
| 5    | 10 mm         | 1.26E-03  | 2          | YES        |       |             |
| 25 mm| 4.14E-04      | 2         | YES        |            |       |             |
| 50 mm| 2.71E-04      | 2         | YES        |            |       |             |
| 100 mm| 7.89E-05     | 2         | YES        |            |       |             |
| 125 mm| 4.98E-05     | 2         | YES        |            |       |             |

As seen in table 8, there are 4 scenarios that the level of risk is in the intolerable region that needed risk mitigation, which are flash fire node 1 with hole diameter scenario 10 mm, flash fire node 2 with hole diameter scenario 10 mm, flash fire node 3 with hole diameter scenario 10 mm, flash fire node 4 with hole diameter scenario 10 mm.

| Scenario Number: Flash Fire Node 2 | Scenario Title: Gas Release for Flash Fire Node 2 at 10 mm | Risk Level: UNACCEPTABLE |
|-----------------------------------|----------------------------------------------------------|--------------------------|
| Date: 12-08-2021                  | Description                                              | Probability              |
| Consequence (Description)         | Fire event                                               |                          |
|                                   | Flash Fire because of gas release incident                |                          |
| Risk Tolerance Criteria (Frequency) | Tolerable risk of a hazard event                          | 1.00E-04                 |
| Initiating Event (Frequency)      | Gas Release                                              | 3.32E-03                 |
| Enabling Event                    | N/A                                                      | N/A                      |
| Conditional Modifiers             |                                                          |                          |
| Ignition Probability              | Delayed Ignition with No Turbulence                      | 7.50E-01                 |
| Frequency of Unmitigated Consequence |                                                        | 2.49E-03                 |
| Independent Protection Layers (IPL) & Probability of Failure on Demand (PFD) | | |
| IPL & PFD                         | Pressure Alarm                                           | 4.22E-02                 |
|                                   | Gas Detector                                             | 1.00E-01                 |
|                                   | Temperature Alarm                                         | 5.52E-02                 |
| Total PFD for all IPLs            |                                                          | 2.33E-04                 |
| Frequency of Mitigated Consequence |                                                          | 5.80E-07                 |
After risk mitigation using LOPA, the frequency of the hazard for the previous 4 scenarios can be lowered. As seen in table 9, The frequency of unmitigated consequence for flash fire node 2 at 10 mm scenario which previously 2.49E-03 can be lowered to 5.80E-07.

4. Conclusion
Based on the fire risk assessment result to the LNG regasification terminal that has been designed, there are 4 scenarios which the risk is in intolerable region, which are flash fire node 1 with hole diameter scenario 10 mm, flash fire node 2 with hole diameter scenario 10 mm, flash fire node 3 with hole diameter scenario 10 mm, flash fire node 4 with hole diameter scenario 10 mm. After mitigation using Layer of Protection Analysis (LOPA), the frequency value for those scenarios can be decreases and the level of risk for the LNG regasification terminal can be accepted.

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