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Hazard Identification of Liquefied Natural Gas (LNG) Transportation and Storage in DKI Jakarta Province

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ABSTRACT

LNG is an alternative fuel to replace diesel and gasoline. The use of LNG as a fuel has many advantages from various aspects. Besides having advantages, LNG also has disadvantages because it contains dangers in it. LNG is a volatile material that is easily flammable, which causes fires and explosions. Environmental Risk Assessment (ERA) is a systematic method used to measure the magnitude of the risk of a process and product that is a hazard to human health and ecology. By conducting an ERA, the risks and hazards of LNG are known. In carrying out the research, describing the LNG delivery system, identifying hazards in the event of LNG released from the carrier, making accident scenarios along with the outcome events that will occur, collecting data, calculating the frequency of accidents and their consequences, determining existing risks, and providing preventive actions, and mitigation. Hazard evaluation was determined using fault tree analysis (FTA) and event tree analysis (ETA). Based on identifying hazards to the storage and transportation of LNG, it is classified into category four and server (severe). Scenarios of releasing LNG into the environment in the process of transporting and storing LNG can be caused by several things, including external factors, failure in filling, and failure due to excess pressure so that it can cause fire pools/BLEVE events, cloud vapor explosions, flash fires, and cloud vapors. Based on the level of risk entered into, not tolerable action at the next opportunity.

1. Introduction

Transportation is one of the basic needs of people in the world. This transportation includes land transportation, sea transportation, and air transportation. In Indonesia today, land transportation plays an important role [1]. In addition to playing an important role, land transportation is widely used for transporting goods or passengers. This can be seen in Figure 1 and Figure 2 below, which state the use of transportation modes in 2013 [2].

From the data in Figure 1 and Figure 2, it can be seen that the most used road is the transportation of goods. Transportation safety is one of the strategic issues in the transportation of goods using roads [3]. This means that the transportation of goods by road has a significant risk of accidents. This risk will be even greater if the material being transported is chemical or hazardous material (which is flammable and reactive) which in the event of an accident will cause the release of the transported material so that it can endanger humans or the environment. The increased risk will be higher if the discharge occurs around the settlement.

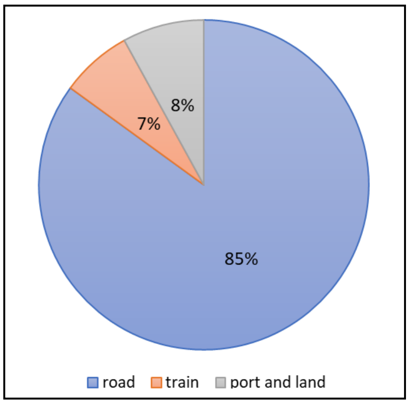


Fig. 1. Percentage of use of passenger transportation modes in 2013

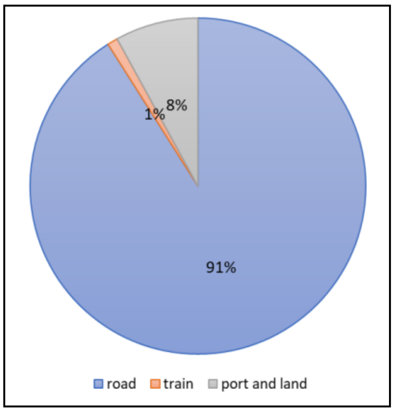


Fig. 2. Percentage of use of goods transportation modes in 2013

Liquefied natural gas (LNG) is an alternative fuel that has the potential to be used in public transportation in Indonesia. Indonesia is a country that has abundant natural gas resources. This is shown from data from the BP Statistical Review of World Energy 2019; natural gas reserves in Indonesia amounted to 50.5 trillion standard cubic feet (TSCF) [4]. In Indonesia in 2018, natural gas production was 2.9 million MMSCF which was used mainly to meet domestic consumption in the industrial sector. In addition, natural gas is used as an export commodity in the form of LNG and piped gas of 1.2 million MMSCF [5]. Seeing the large reserves and fixed production capacity, LNG can be used as an alternative fuel in Indonesia to reduce gasoline and diesel consumption. In addition, the emission produced from LNG is lower, so it is environmentally friendly.

Liquefied natural gas (LNG) can be transported using cryogenic tankers or pipelines. However, the pipeline network has several drawbacks, including the pipeline cannot be placed below 100 m above sea level, expensive investment, high risk, inflexibility in transport capacity, and gas supply depending on the pressure drop along the pipeline. The pressure drop in the pipe ranges from 7-10 bar every 160 km [6], so it is more profitable if transported using a cryogenic tanker and stored in a storage tank.

The transportation and storage of LNG must carry out a hazard evaluation in the form of identification, determination of scenarios that have the potential to produce hazards, and determination of the probability of occurrence of hazards and their consequences. The method that can be used to evaluate the dangers of transporting and storing LNG is by using Fault Tree Analysis (FTA) and Event Tree Analysis (ETA). FTA and ETA are two different methods for determining QRA, which develop a logical relationship between the events that caused the accident and estimate the risk associated with the accident. ETA is a technique used to describe the consequences of an event (initiating event) and estimate the likelihood (frequency) of the possible outcomes of that event. FTA represents the basic causes of undesired events and estimates the probability (probability) and contributions of various causes that lead to undesired events. In FTA, the underlying cause is called the base event, and the undesired event is called the culmination event [7]. Therefore, in this study, FTA and ETA were created to evaluate the transport and storage of LNG.

2. Research Methodology

2.1. Materials

The data used in this study is the volume of LNG tanks, earthquakes that occurred in Indonesia, and the failure rate that causes the release of LNG to the environment.

2.2. Procedures

1. Describe the LNG delivery system
2. Carry out hazard identification
3. Carry out accident scenarios
4. Obtaining probability value
5. Determine the level of risk of the incident

3. Result and Discussion

2.3. LNG Distribution

LNG procurement starts from the LNG plant, which is then transported to the LNG terminal, and then the gas is distributed to consumers, as shown in Figure 3.

1) LNG Plant

The LNG plant is a facility where the gas liquefaction process occurs in LNG. LNG plants are usually located close to gas sources. Before liquefaction, the gas will go through a purification process, namely the disposal of acid gas, dehydration, disposal, mercury removal, and other contaminants. The liquefaction process is used to deliver gas to customers far away from the gas source or areas the pipeline network has not reached.

2) FSRU

FSRU is a special type of ship used for LNG transfer capable of transporting, storing, and regasifying LNG on board. FSRU is a more economical and flexible alternative to LNG regasification facilities for storage and regasification systems. The cost of an FSRU is less than a land facility of the same capacity; in addition, the FSRU can be moved from one area of demand to another, so accidents on one landmass may have less impact on the population when compared to onshore installations.

3) Onshore Receiving Facilities (ORF)

In these onshore receiving facilities, LNG that has been regasified at the FSRU is further processed before being forwarded to the customer. Several processes occur in this ORF; namely, gas from the FSRU enters the filter and then is heated with an indirect fired water bath heater (IFWBH) after passing through the metering system and lowering the pressure using a pressure let down valve before the gas is delivered to the user.

4) LNG Small FSRU

It is an FSRU with a smaller storage capacity and is used for smaller energy requirements.

5) LNG Base Receive Terminal

It is an onshore receiving facility that functions to store LNG. From the LNG base to receive terminal, it is then distributed either using a tanker transporting LNG or through a pipe in the form of gas.

6) LNG Bunker For Marine

It is a facility that stores, distributes, and refills LNG as ship fuel.

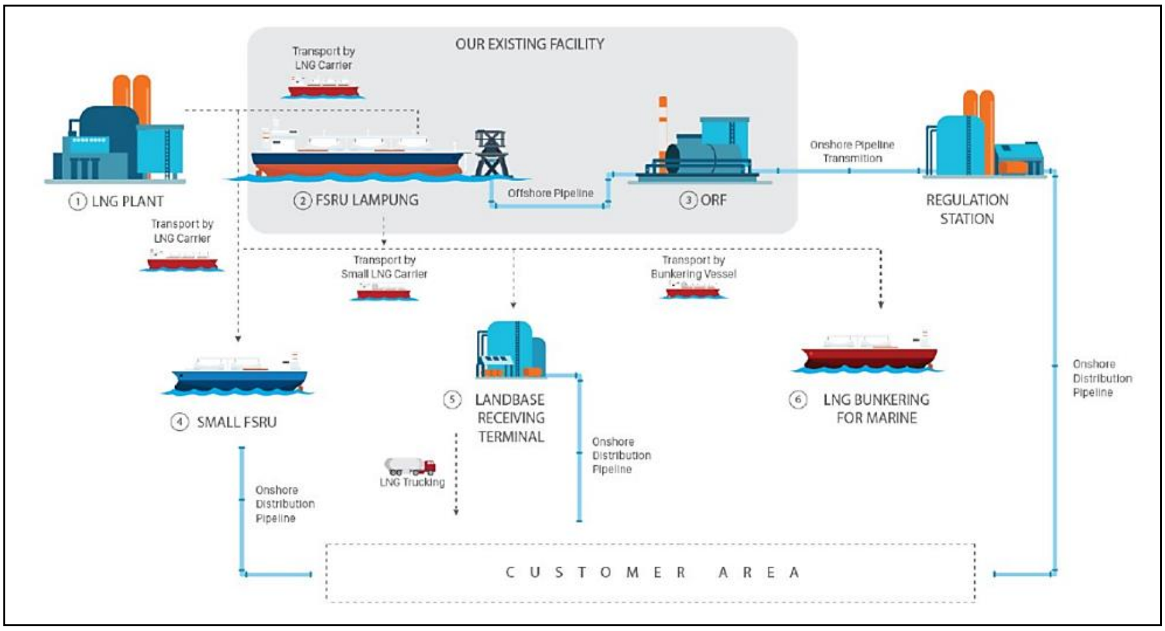


Fig. 3. Upstream to downstream LNG[8]

2.4. LNG Hazard Identification

LNG is a category 1 flammable gas or flammable gas category 1, liquids and gases that are highly flammable, very cold, and form explosive mixtures in air and with oxidizing agents. At high temperatures and LNG, fire conditions can form carbon monoxide and carbon dioxide, and a fireball is formed if the gas is ignited immediately after being released. The method used to classify the hazard on LNG can use risk criteria and the Dow's Fire and Explosion Index (F&EI).

1) *Risk Criteria*

The volume of LNG in the tank used in this study was 49,225 lb. The LNG release characteristics based on the Material Safety Data Sheet [9] were bellows BP and Flammable BP. With this data, the category of risk that occurs is then determined. From Table 1, based on the known release characteristics and volume of LNG in the tank, it can be concluded that the LNG in the transport tank falls into category 4.

Table 1. Risk Criteria [10]

Consequence Size / Release Characteristic	**1- to 10-pound Release**	**10- to 100-pound Release**	**100- to 1,000-pound Release**	**1,000- to 10,000-pound Release**	**10,000- to 100,000-pound Release**	**>100,000-pound Release**
*Extremely toxic, above B.P. **	Category 3	Category 4	Category 5	Category 5	Category 5	Category 5
Extremely toxic, below B.P. or Highly toxic, above B.P.	Category 2	Category 3	Category 4	Category 5	Category 5	Category 5
High toxic, below B.P. or Flammable, above B.P.	Category 2	Category 2	Category 3	Category 4	Category 5	Category 5
Flammable, below B.P.	Category 1	Category 2	Category 2	Category 3	Category 4	Category 5
Combustible liquid	Category 1	Category 1	Category 1	Category 2	Category 2	Category 3

*. B.P. = atmospheric boiling point

2) *Dow's Fire and Explosion Index (F&EI)*

Dow's Fire and Explosion Index (F&EI) is one method that can be used to identify the dangers of chemical compounds, one of which is LNG. Based on Table 2, it can be concluded that the transportation and storage of LNG are categorized as severe.

Table 2. Dow's Fire and Explosion Index (F&EI)

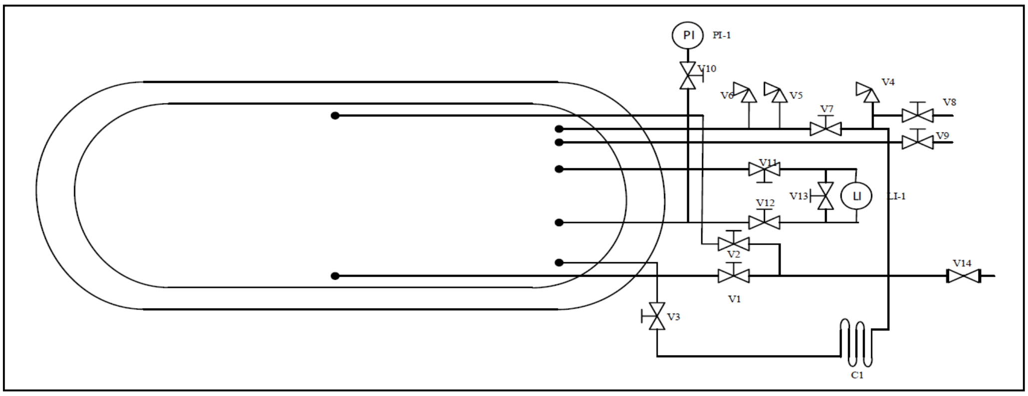
Material Factor	General Process Hazard Factor (F_1)	Special Process Hazard Factor (F_2)	Process Unit Hazard Factor (F_3)	*Dow's Fire and Explosion Index* (F&EI)
21	4.85	9	43.65	916.65

2.5. LNG Release Scenarios

The LNG release scenario is based on LNG transportation to DKI Jakarta and LNG storage in DKI Jakarta. A fault tree analysis (FTA) chart is used to analyze the release of LNG in the tank. The release of LNG into the environment can be caused by several reasons, one of which is the occurrence of an earthquake. The earthquake referred to here is an earthquake that caused severe damage in the DKI Jakarta Province. From the data obtained from 1963 to 2018, there were 27 earthquakes in DKI Jakarta Province, as shown in Table 3. The frequency of earthquakes was obtained based on earthquake data, which was 0.4909 events/year.

Table 3. Earthquake in DKI Jakarta Province [11]

No.	Years	Scale	Magnitude Scale
1	2018	IV-V MMI	6.4
2	2017	II – III MMI	6.9
3	2014	II MMI	6.5
4	2012	II – III MMI	5.7
5	2010	II-III	6.0
6	2010	II	6.3
7	2009	II	7.6
8	2009	II	7.0
9	2007	IV	6.9
10	2007	III	7.9
11	2007	III	7.7
12	2007	III	7.0
13	2006	IV	6.8
14	2004	II	7.3
15	2002	II	6.5
16	2001	II	6.9
17	2001	II	7.4
18	2000	III	7.3
19	2000	III	6.5
20	2000	III	5.1
21	1999	IV – V	6.0
22	1997	IV – V	6.0
23	1994	II	6.6
24	1990	II	5.8
25	1974	VI	6.1
26	1969	V	5.4
27	1963	V	5.0



Where:

V1	: front filling	V10	: hand shut off valve
V2	: top filling	V11, 12, 13	: special valve
V3	: pressure builing valve	V14	: purge valve
V4, 5, 6	: safety valve	PI-1	: pressure gauge
V7, 8	: vent valve	LI-1	: level gauge
V9	: trycock valve	C1	: pressure building coil

Fig. 4. LNG transport tank P&ID [12]

Based on Figure 4, other scenarios that cause LNG release can also be made because the level indicator fails to work, the pressure indicator fails to work, the pressure regulator fails to work, the vent valve fails to open, the filling valve fails to close, the safety valve fails to open, and the operator fails to see pressure/level indicator failed to take action.

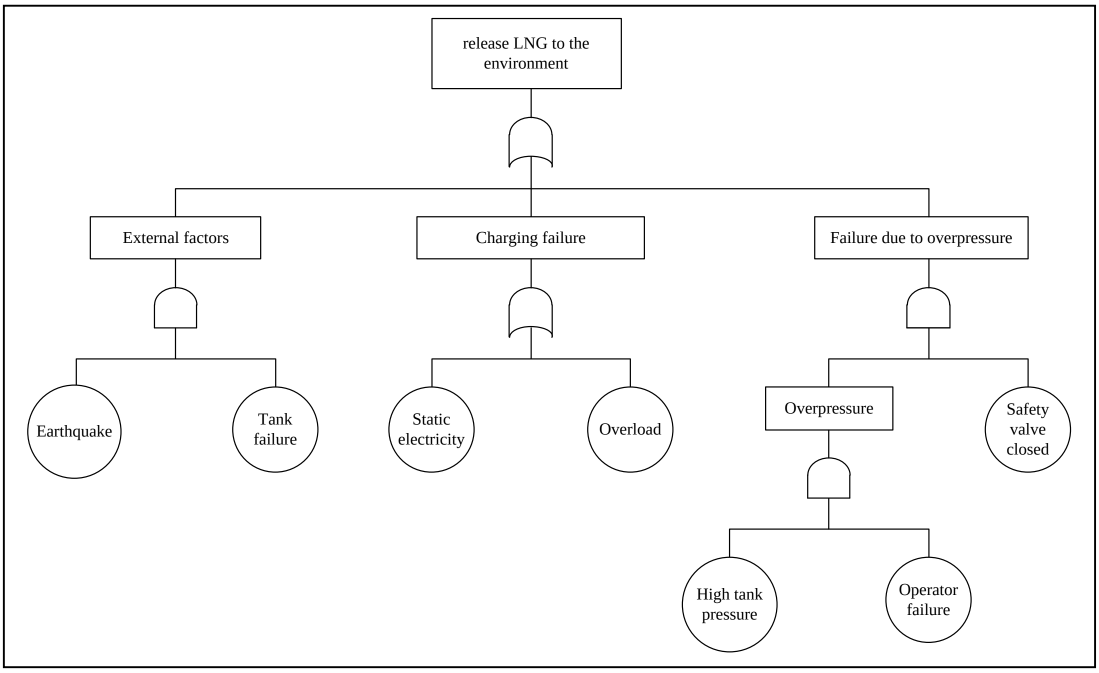


Fig. 5. LNG transport and storage FTA

Based on the analysis carried out, the greatest probability of failure is due to an earthquake which is then followed by the pressure indicator failing to work, the pressure setting failing to work, the level indicator failing to work, the vent valve failing to open, the filler valve failing to close, and the safety valve failing to open. The failure rate influences the probability of this failure. The greater the failure rate, the greater the probability of failure.

Table 4. Failure rate and probability of failure

Description of Cause	Failure Rate (failure/year)	*reliability* (per year)	*Failure Probability* (per year)
Earthquake	0.4909	0.6121	0.3879
Indicator level failed to work [13]	4.599×10^{-2}	0.9951	0.0049
Pressure indicator failed to work [13]	5.414×10^{-2}	0.9473	0.0527
Pressure regulator failed to work [13]	1.086×10^{-2}	0.9892	0.0108
Vent valve failed to open [13]	1.139×10^{-3}	0.9989	0.0011
Fill valve failed to close [13]	1.051×10^{-3}	0.9989	0.0011
Safety valve failed to open [14]	2.19×10^{-4}	0.9998	0.0002

2.6. Event Risk

An incident analysis was carried out first to determine the consequence's frequency. The analysis of the LNG release event can be seen in Figure 5.

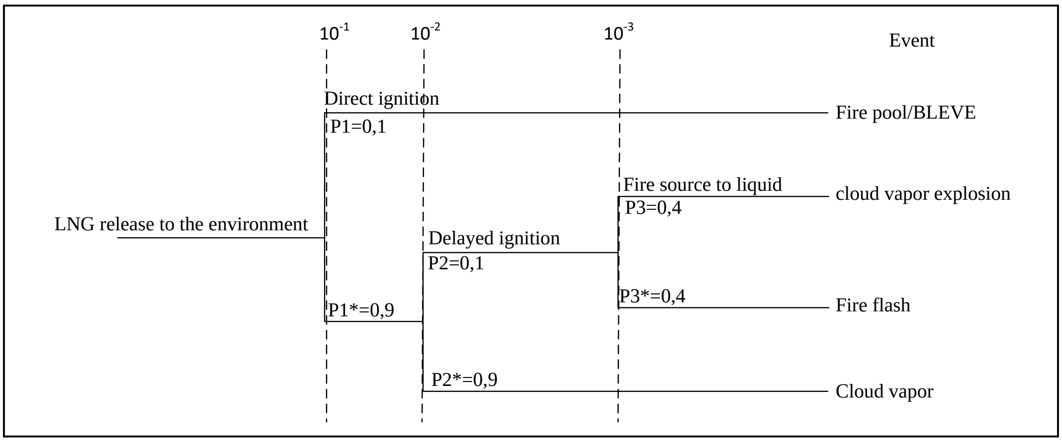


Fig. 6. ETA of releases LNG to the environment[15]

Based on the BVI risk assessment reference manual, the release of LNG into the environment can cause a fire pool/BLEVE, cloud vapor explosion, flash fire, and cloud vapor. From this incident, it can be concluded that the frequency of occurrence is 10-3. From the material category and the occurrence frequency, the incident's risk level is obtained, as shown in Table 5.

Table 5. The risk level of the incident

Frequency of Consequence	Consequence Severity Category				
	Category 1	Category 2	Category 3	Category 4	Category 5
10^{-1} - 1 (per year)	tolerable if ALARP - evaluate alternatives	tolerable if ALARP - evaluate alternatives	NOT TOLERABLE - ACTION AT NEXT OPPORTUNITY	NOT TOLERABLE - IMMEDIATE ACTION	NOT TOLERABLE - IMMEDIATE ACTION
10^{-2} - 10^{-1} (per year)	tolerable if ALARP - evaluate alternatives	tolerable if ALARP - evaluate alternatives	tolerable if ALARP - evaluate alternatives	NOT TOLERABLE - ACTION AT NEXT OPPORTUNITY	NOT TOLERABLE - IMMEDIATE ACTION
10^{-3} - 10^{-2} (per year)	tolerable - no action required	tolerable if ALARP - evaluate alternatives	tolerable if ALARP - evaluate alternatives	NOT TOLERABLE - ACTION AT NEXT OPPORTUNITY	NOT TOLERABLE - ACTION AT NEXT OPPORTUNITY
10^{-4} - 10^{-3} (per year)	tolerable - no action required	tolerable - no action required	tolerable if ALARP - evaluate alternatives	tolerable if ALARP - evaluate alternatives	NOT TOLERABLE - ACTION AT NEXT OPPORTUNITY
10^{-5} - 10^{-4} (per year)	tolerable - no action required	tolerable - no action required	tolerable - no action required	tolerable if ALARP - evaluate alternatives	tolerable if ALARP - evaluate alternatives
10^{-6} - 10^{-5} (per year)	tolerable - no action required	tolerable - no action required	tolerable - no action required	tolerable - no action required	tolerable if ALARP - evaluate alternatives
10^{-7} - 10^{-6} (per year)	tolerable - no action required	tolerable - no action required	tolerable - no action required	tolerable - no action required	tolerable - no action required

The results obtained from determining the level of risk are not tolerable actions at the next opportunity, which means previous risky actions must be avoided or reduced so that the desired things do not happen and choices are made for new scenarios.

4. Conclusion

Several scenarios can cause LNG to be released into the environment during transportation, including external factors, failure of filling, and overpressure. The release of LNG into the environment can cause several things, namely fire pools/BLEVE, cloud vapor explosions, fire flashes, and cloud vapors. Based on identifying the dangers of transporting and storing LNG, it is categorized as 4 and severe, and the level of risk is intolerable. LNG transportation and storage remain safe to implement by carrying out all appropriate standard operating procedures.

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