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Risk analysis of gas dispersion, fire and explosion due to gas pipeline leak at Onshore Receiving Facility of PT XYZ in Muara Karang using Aloha Software 5.4

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Abstract
This research identifies hazards, assesses risks, and recommends mitigations for the risk of gas pipeline leaks at Onshore Receiving Facility (ORF). The objectives of this study are to determine the probability of gas pipeline leaks at ORF and the level of risk of gas pipeline leaks at ORF using a risk matrix, to model gas dispersion, fire, and explosion using ALOHA software to assess the consequences of gas pipeline leaks at ORF, and to provide risk mitigation recommendations to the company if the risk level is unacceptable and the existing risk mitigation measures are not effective. This study is qualitative research in which the author develops a model from theoretical framework to conceptual framework, and then describes the results of the analysis descriptively. The hazard identification approach used historical data from the Hazard Operability's Study (HAZOP) data, which found that the highest risk level was gas pipeline leaks in pipelines with a pressure of 350 psi. The probability of pipeline leaks was obtained from the Generic Failure Frequency (GFF) table from the existing Risk-Based Inspection (RBI) study. Consequence analysis was performed using modeling software ALOHA and MARPLOT with gas dispersion, fire, and explosion scenarios. The analysis showed that the risk level of gas dispersion, fire, and explosion scenarios were all still acceptable, referring to the criteria of NFPA 59A. Therefore, it can be concluded that the risk level of gas pipeline leaks at ORF is still acceptable, and the existing risk mitigation measures are sufficient.

1. Introduction

To meet natural gas needs, gas imports are needed starting in 2023 and gas net importers are expected to occur in 2028. In 2050 it is estimated that natural gas imports will reach 4,441 BCF. Imports that continue to increase have the consequence of the need for infrastructure support, especially the Floating Storage Regasification Unit (FSRU). The utilization of natural gas for energy transformation activities is dominated by the electricity generation sector. Natural gas is used to meet the fuel needs of basic or medium load power plants and peak loads. The demand for natural gas for electricity generation is estimated to continue to increase with a growth of 4.9% per year due to the large number of Gas Power Plants (PLTG) and Steam Gas Power Plants (PLTGU) in the 35,000 MW electricity program (Pengkajian & Teknologi, 2018).

LNG that has been regasified is received at the Onshore Receiving Facility. The gas is then distributed through a distribution pipe to the Gas Power Plant (PLTG) and Steam Power Plant (PLTGU)

The occurrence of gas leak accidents, fires and explosions is quite common in gas pipeline facilities, from 2018 to 2019 there were several events as follows.

- October 26, 2018, PGN gas pipeline leak in Ngagel, Surabaya caused fires, explosions, damage to facilities and several injured people were cited from online media.
- February 22, 2019, cited from online media, an explosion at Taman Anggrek Mall occurred, injuring seven people, the explosion also damaged 12 counters and 2 shop houses.
- April 23, 2019, cited from online media, due to a leaking gas pipe, the fire burned a house on Jalan Kayu Mas Timur RT7 RW3 Kelurahan / Pulogadung District, Jakarta.

From the incident series above, the probability that the incident can occur at PT XYZ Facility. Therefore, a risk analysis is needed to determine the frequency, consequences and risk level if there is a gas pipeline leak at the Muara Karang ORF and provide risk mitigation recommendations to the company.

Risk analysis (risk assessment) is a method used to determine how much risk and danger will occur in an object by performing calculations, both frequency and consequence. Frequency analysis is carried out using historical data or refers to standards. The consequence analysis is done using fire modeling with ALOHA software based on existing data. From the two parameters, the level of risk will be obtained which is then represented in the risk matrix(Devi et al., 2017).

Unacceptable risks must be given a mitigation process to reduce the value of frequency and consequences so can decrease the level of risk.

Formulation of the problem

1. How much is the probability of an ORF gas pipeline leak.
2. What is the level of consequence of ORF gas pipeline leak by modeling gas dispersion, fire and explosion using ALOHA software.
3. What is the level of risk of ORF gas pipeline leak referring to the risk matrix.
4. What risk mitigation recommendations will be submitted to the company if the level of risk is not acceptable and the existing risk mitigation is not yet effective.

Research purposes This research aims to :

1. Analyze the probability of an ORF gas pipeline leak.
2. Analyze the consequences of the ORF gas pipeline leak by modeling gas dispersion, fire and explosion using ALOHA software.
3. Analyze the risk level for ORF gas pipe leakage with the risk matrix.
4. Provide risk mitigation recommendations to companies if the level of risk is unacceptable and mitigation of existing risks has not been effective.

This research is expected to be able to provide benefits to the world of education, industry and society in general.

2. Literature review

Gas explosions can start from leaking gas and or liquid from a storage area. If the leak is formed a gas cloud mixture with a ignition process is delayed then a gas explosion occurs(Bjerketvedt et al., 1997). Here's a scheme that can explain the occurrence of a gas explosion:

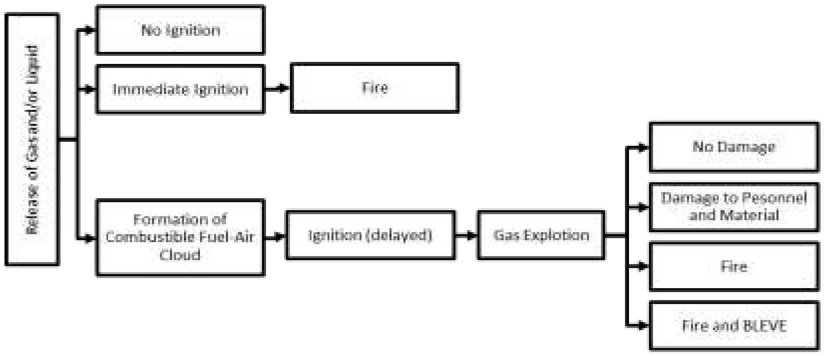


Figure 1. Gas explosion process

2.1. Hazard identification

Hazard is a situation with a potential to cause accidents to human, environmental and equipment safety. Can be a physical situation, an activity or a material. In practice hazard is often used for combinations of physical situations with certain conditions that might cause accidents. The essence of hazard is the existence of a potential that causes an accident, without seeing things that are acceptable or unacceptable that occur(Standard & IEC, 2003).

HAZOP (Hazard and Operability Study) is a recommended method for identifying hazards and problems that can interfere with operations. HAZOP is a technique that provides an opportunity

People can think freely about how danger or operating problems can arise. HAZOP studies carried out in a systematic way by the team.

2.2. Probability analysis

Estimates of probability begin with conducting a literature study on the research that has been done before and on existing data. From the literature study, we will analyze how many probabilities will occur in each event. Furthermore the frequency is obtained by doing calculations based on the existing scenario. Scenarios are based on logical assumptions so that the likelihood of occurrence of a risk event can be accepted and the frequency value obtained can also be used to make decisions.

2.3. Consequence Analysis

The consequence analysis was carried out with ALOHA software, Determination of Level Of Concern on fire and explosion models. In the fire model, the Thermal Radiation Level of Concern or thermal radiation level threshold consists of a red zone: 10 kw / m2 (potentially lethal within 60 seconds), orange zone: 5 kw / m2 (second- degree burns within 60 seconds) , and yellow zone: 2 kw / m2 (sick) within 60 seconds). Whereas Overpressure Level of Concern or pressure threshold level of the explosion wave consists of red zone: 8.0 psi (causing buildings to be destroyed), orange zone: 3.5 psi (probability of serious injury), and yellow zone: 1.0 psi (can cause broken glass.

To estimate the consequences of the facilities used by MARPLOT, a mapping program that is widely used to plan and respond to chemical / hazardous emergencies, to display estimates of the ALOHA threat zone on the map(MANUAL, 2007b).

2.4. Risk Assessment

Risk assessment is carried out by identifying events that might occur and providing hazard values on a certain scale. After identifying the event that might occur, the frequency calculation and the consequences that may occur on each event are carried out. From the identification of the consequences and calculation of frequency, a risk matrix can be found that shows the position of the risks that may occur in the object, whether the risk is acceptable or not(IDRUS, n.d.).

In the risk matrix, the consequences and probability categories are arranged so that the highest risk component is in the upper right corner. Probability category of consequences and consequence categories expressed in each area. Risk categories (high, medium high, medium, and low) are described in the box in the risk matrix .

Risk reduction efforts must be balanced with an analysis of the costs. If the risk estimates are still unacceptable, then efforts to reduce risk can be done in 3 ways, including:

1. Reducing frequency
2. Reducing consequences, or
3. A combination of both.

Risks must be made to be as small as possible (in the green zone), meaning that after risk reduction is done, it should also be considered in terms of costs. The risk is kept acceptable and followed by the lowest cost. Frequency reduction calculations must be prioritized before the calculation of consequence reduction [2].

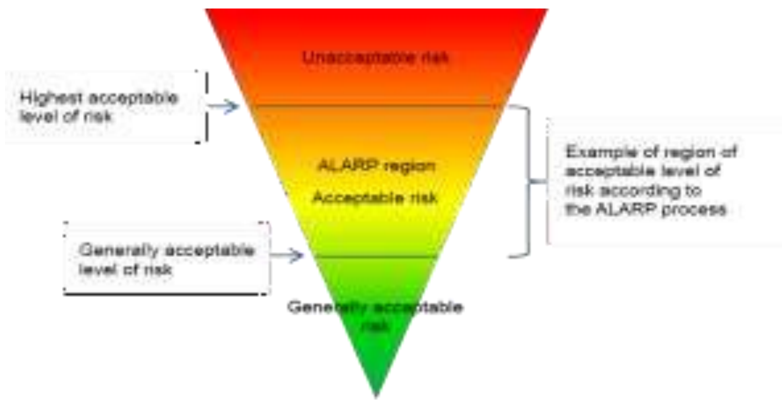


Figure 2. Risk acceptance criteria [2]

2.5. Risk Matrix and Risk Acceptance Criteria

In accordance with NFPA 59A, the table below can be used as a benchmark in determining risk in the risk matrix. This risk matrix will determine the position of a risk, whether the risk is acceptable or not. The table below is a risk matrix in accordance with NFPA 59.

Table 1. NFPA 59A frequency category

Probability class	Occurance frequency per year
1	$>10^{-1}$
2	10^{-1} - 10^{-2}
3	10^{-2} - 10^{-3}
4	10^{-3} - 10^{-4}
5	10^{-4} - 10-^{5}
6	10^{-5} - 10^{-6}
7	$<10^{-6}$

Table 2. NFPA 59A consequence catagory

Consequence Category	1	2	3	4	5
Number of injuries	>100	10-100	1-10	0.1-1	<0.1

Table 3. Risk matrix NFPA 59A

Anual cumulative frequency		Consequence category				
Class	Range	5	4	3	2	1
1	$>10^{-1}$	AR	NA	NA	NA	NA
2	10^{-1} - 10^{-2}	AR	AR	NA	NA	NA
3	10^{-2} - 10^{-3}	A	AR	AR	NA	NA
4	10^{-3} - 10^{-4}	A	A	AR	AR	NA
5	10^{-4} - 10^{-5}	A	A	A	AR	AR
6	10^{-5} - 10^{-6}	A	A	A	A	AR
7	$<10^{-6}$	A	A	A	A	A

Catatan : A = Acceptable ; AR = ALARP ; NA = Not Acceptable

3. Materials and Methods

This research is qualitative research, the data collected includes information about the design of the Muara Karang Facility Onshore Receiving (ORF) facility, as well as other data needed such as meteorological data, location, and scenario. These data are obtained through literature studies and browsing on the internet. The conceptual framework of this research is described as follows:

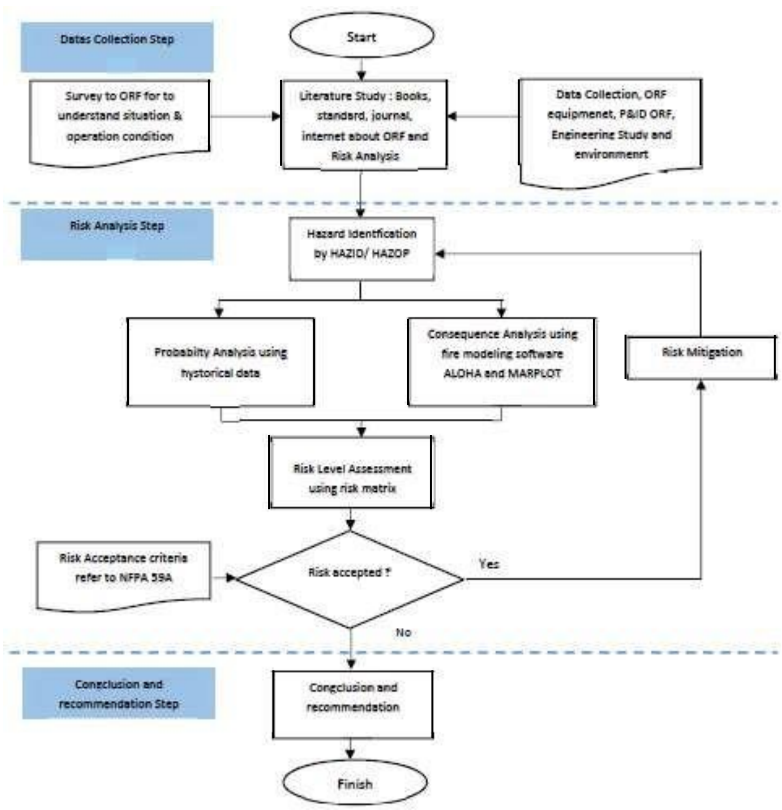


Figure 3. Conceptual Framework

In the study there are 5 variables, namely (1) Source of Gas Leaks, (2) Atmospheric Data, (3) Chemical Data, (4) Scenarios and (5) Output of each variable operationally explained as follows:

Table 4. Operation Definitions

NO	VARIABLE	DEFINITION	MEASUREMENT	RESULT	SCALE
1	*Hazard Identification*	*The process of knowing what hazards might occur*	*Historical Data (Study HAZID & HAZOP)*	*Scenario*	*Ordinal*
2	*Probability Analysis*	*The process determines how likely an event will occur*	*Historical Data (RBI Table gff) and NFPA 59A Consequences Table*	*Probabilities Class (1 to. 7)*	*Ordinal*
3	*Consequence Analysis*	*The process of calculating the impact of an event*	*Software ALOHA dan MARPLOT Modelling and NFPA 59A Consequence Table*	*Consequences Catagory (1 to 5)*	*Ordinal*
4	*Risk Level Assessment and Risk Acceptance Criteria*	*The process of knowing the level of risk and determining whether it is acceptable or not*	*NFPA 59A Risk Matrix*	• *Not acceptable* • *ALARP* • *Acceptable*	*Ordinal*

4. Results and Discussions

Regasification LNG was received at the Muara Karang Onshore Receiving Facility (ORF) at a pressure of 45 barg. Facilities designed for a capacity of 500 MMSCFD. During normal operation, the gas flow rate can vary from 100 to 400 MMSCFD. Gas will be distributed to PTABC as the main user, PTDEF and PTHIJ. Gas will be sent to PTABC Muara Karang at pressure of 42.7 barg and 24 barg; and to PTABC Tanjung Priuk at a pressure of 26 barg. Minimum temperature of gas arrival required is 10oC to meet PTABC requirements. To achieve this minimum arrival temperature, minimum offshore gas heat is required at 15oC.

Hazard identification is done by approaching the study of relevant historical data, in this study the authors identified the danger to determine the scenario referring to the HAZOP Study data.

Estimation of probability is done by conducting a literature study on research that has been done before from existing data, in this study data is taken from the Risk Based Inspection (RBI) study report. From the literature study, it will be analyzed how much frequency will occur in each event. Besides using existing data. Scenarios are based on logical assumptions so that the probability of occurrence of a risk event can be accepted and the frequency value obtained can also be used to make decisions on the final results.

Generic failure frequency (gff) of a component is measured using historical data from all plants inside the company or from several plants in certain industries. The generic failure frequency (gff) that will be used in this case is taken from the API-RP581 database as seen in Table 4.4. outline(Shishesaz et al., 2013).

Table 5. Gff of selected equipment's and components

Tipe Peralatan	Tipe Komponen	*gff*_dalam Fungsi Ukuran Lubang, (kegagalan/tahun)				Gff total, (kegagalan/ tahun)
		Kecil (0 – ¼ inci)	Sedang (>¼ – 2 inci)	Besar (>2 – 6 inci)	Pecah (> 6 inci)	
Compressor	COMPC	8.00E-06	2.00E-05	2.00E-06	0	3.00E-05
Compressor	COMPR	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXSS	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXTS	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXTUBE	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-1	2.80E-05	0	0	2.60E-06	3.06E-05
Pipe	PIPE-2	2.80E-05	0	0	2.60E-06	3.06E-05
Pipe	PIPE-4	8.00E-06	2.00E-05	0	2.60E-06	3.06E-05
Pipe	PIPE-6	8.00E-06	2.00E-05	0	2.60E-06	3.06E-05
Pipe	PIPE-8	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-10	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-12	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-16	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPEGT16	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/FinFan	KODRUM	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/FinFan	COLBTM	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/FinFan	FINFAN	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

Calculation of probability of failure (PoF), as below :
GFF = 3.06 x 10^{-5} (form GFF table)
Damage Factor Total (DFTotal)

Internal Thinning Damage Factor (DFIT)Age (year between measurement date and RBI date), A = 3.06 year Inspection Data (UT measurement) Thickness at measurement date (11 December 2014), t1: 25.18 mm Inspection Effectiveness: C, Number of Inspection: 2 (2014, 2017)

Corrosion Rate (r)

The thickness measurement in 2017 shows the minimum thickness is greater than previous thickness.

$r=(t\_2-t\_1)/(Year\ between\ measurement\ thickness)$
$r=(26.00-25.18)/3.945$ $r=0.208\ mmpy$
$Ar/t=max=\{0,(1-(t\_(min,last\ inspection)-Ar)/t\_(min,prev\ insp))\}$
$Ar/t=max=\{0,(1-(25.18-(3.06\times0.208))/26.00)\}$ $Ar/t=0.056$
Value Ar/t between 0.04 and 0.06

DFIT = 1
Result for Damage Factor Total:
DFIT = 1, DFET = 1 → DFET = 0, DFC = 0, DFMF = 0
DFTotal = DFIT + DFET + DFC + DFMF = 1 + 0 + 0 + 0 = 1

Referring to API RP 581, if the damage factor is less or equal to 1, the damage factor must be set to 0. If the damage factor is less or equal to 1 then the total DFT must be set to 1.

Results for PoF
PoF = GFF x DFTotal = 3.06 X 10-5 x 1 = 3.06 X 10-5= **3.06 event/100000 year**

Table 6. Risk Probability

Probability class	Occurance frequency per year
1	$>10^{-1}$
2	10^{-1} - 10^{-2}
3	10^{-2} - 10^{-3}
4	10^{-3} - 10^{-4}
5	10^{-4} - 10^{-5}
6	10^{-5} - 10^{-6}
7	$<10^{-6}$

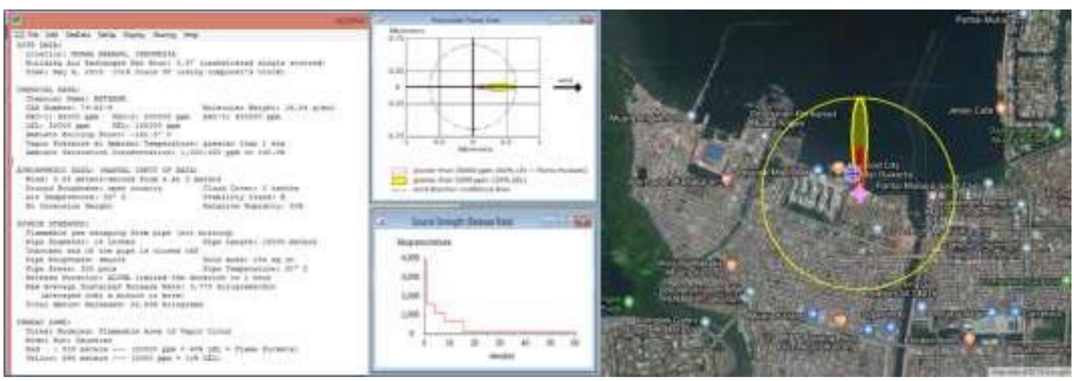
From the results of calculation, the probability class = 5

Estimated consequences are carried out by doing a modeling simulation using ALOHA software(MANUAL, 2007a). The software is used to calculate the consequences that may occur in each scenario that is made, the software will produce a result that shows how much consequences are generated due to the causes of risks that occur in the gas pipeline leak at ORF. These consequences can be in the form of heat flux that occurs around the scene and the number of people who will experience injury or death or damage to facilities / equipment due to the incident. The scenario was chosen based on the identification of hazards from the HAZOP ORF study conducted by the Company, where the biggest risk was the gas pipeline leak on line 350 with the scenario of rupture pipeline leakage.

To get the consequence number, the results of the modeling in the form of the number of injured people will be compared with the consequences of NFPA 59A to see the category of consequences.

Data inputted into ALOHA software is obtained as follows:

- Site Data: Location: Muara Karang, Indonesia. Date and time: 6 May 2019 at 13.16
- Chemical Data: Name: Methane CAS Number: 74-82-8 LEL: 50000 ppm UEL: 15000 ppm
- Atmospheric data: Wind Speed: 0.85 meters / second Altitude: 3 meters Temperature: 30° C, Humidity: 50%.



5.

Figure 4. Gas Dispersion Model

- Gas dispersion with 60% LEL (30000 ppm) as far as 318 meters from the source of the leak.
- Gas dispersion with 10% LEL (5000 ppm) as far as 644 meters from the source of the leak

From the two scenarios, the farthest dispersion is 644 meters with 10% LEL (5000 ppm) pointing north or to sea, so it can be concluded that if there is a leak, if there are workers in the gas dispersion pathway it will cause respiratory problems but the gas dispersion has no consequence to the area public around ORF(Council, 2003).

The results of the gas dispersion modeling analysis the consequence rating is obtained = 4

Jet fire can arise due to gas release. In the picture below shows the area of thermal radiation from the jet fire source in the scenario of a rupture gas pipeline leak. The chemical compound that burns is methane gas, while the wind direction comes from the east. Duration of 1 hour release time with burn rate 92376 pounds / min and total burn of 55,382 pounds. The consequences caused by the simulation leak point can be seen in the threat zone, as follows:

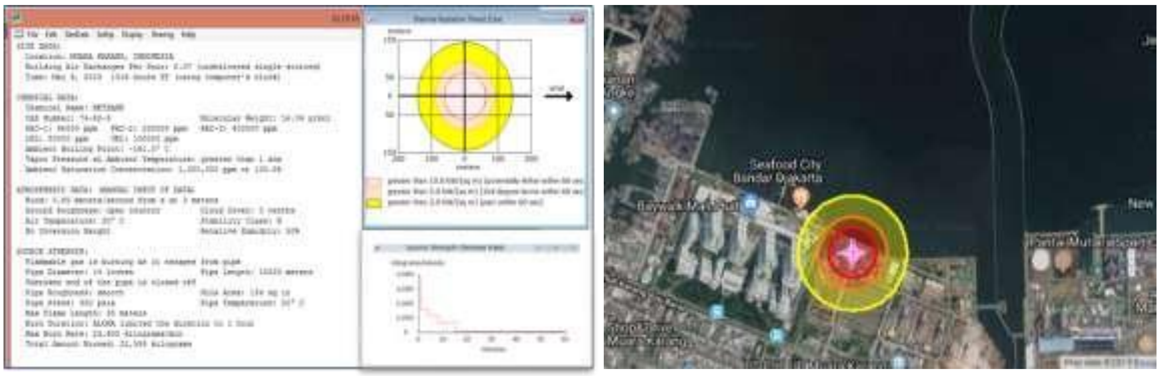


Figure 5. Fire modelFrom the results of the simulation in the software, the consequences of heat radiation from fires in the event of an ORF gas pipeline leak from PT XYZ in Muara Karang.

- The consequence of fire heat radiation is 10 kw / m2 which has a fatal / fatal consequence to humans the farthest distance from the center of the gas leak is 388 meters.
- The consequences of fire heat radiation are 5 kw / m2, the probability of level 2 burns to humans the farthest distance from the gas leak center is 561 meters.
- The consequence of fire heat radiation is 2 kw / m2 which has the consequence of the possibility of minor burns / level 1 to humans the farthest distance from the gas leak center is 898 meters.

From the two scenarios if there is a gas leak that causes a fire in ORF the consequences of the heat radiation of probability fires will have fatal / death consequences in the Industrial area (industrial facilities around ORF) while the probability of having consequences for public areas is level 2 and level 1 with radius furthest 898 meters. The results of the gas dispersion modeling analysis have consequences = 3

Explosions can occur as a result of gas vapor fog. In the picture above shows the distribution area of the steam cloud. Data inputted into ALOHA software is obtained as follows:

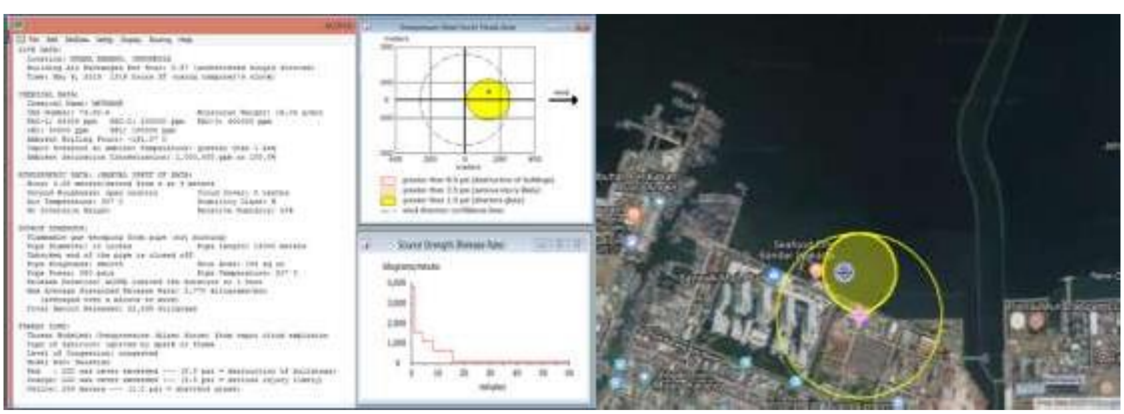


Figure 6. Explosion model

From the software simulation results the consequences of an explosion if an gas pipeline leak occurs in ORF Muara Karang.

- The consequence of an explosion with a pressure of 10 psi which is the probability of damage to the building is not detected.
- The consequence of an explosion with a pressure of 3.5 psi, the probability of damage to the building is not detected.
- The consequence of an explosion with a pressure of 1 psi, which has the probability of breaking glass in a building with the furthest explosion radius of 258 meters.

From this scenario, if there is a gas leak that causes an explosion at ORF, the consequence of a probability explosion is the breakdown of glass in the building towards the north (sea). The results of the gas dispersion modeling analysis have consequences = 4

4.1. Risk level analysis

Risks received with gas dispersion scenarios are based on the number of human victims affected by the accident. The following assessment is obtained based on the results of the analysis:

Table 7. Risk analysis for gas dispersion scenario

Anual cumulative frequency		Consequence category				
Class	Range	5	4	3	2	1
1	$>10^{-1}$	AR	NA	NA	NA	NA
2	10^{-1} - 10^{-2}	AR	AR	NA	NA	NA
3	10^{-2} - 10^{-3}	A	AR	AR	NA	NA
4	10^{-3} - 10^{-4}	A	A	AR	AR	NA
5	10^{-4} - 10^{-5}	A	A	A	AR	AR
6	10^{-5} - 10^{-6}	A	A	A	A	AR
7	$<10^{-6}$	A	A	A	A	A

Catatan : A = Acceptable ; AR = ALARP ; NA = Not Acceptable

Risks received with gas dispersion scenario based on the number of human victims affected by the accident. The following assessment is obtained based on the results of the analysis:

Risks received with fire scenarios based on the number of human victims affected by the accident. The following assessment is obtained based on the results of the analysis:

Table 8. Risk analysis for fire scenario

Anual cumulative frequency		Consequence category				
Class	Range	5	4	3	2	1
1	$>10^{-1}$	AR	NA	NA	NA	NA
2	$10^{-1} - 10^{-2}$	AR	AR	NA	NA	NA
3	$10^{-2} - 10^{-3}$	A	AR	AR	NA	NA
4	$10^{-3} - 10^{-4}$	A	A	AR	AR	NA
5	$10^{-4} - 10^{-5}$	A	A	A	AR	AR
6	$10^{-5} - 10^{-6}$	A	A	A	A	AR
7	$<10^{-6}$	A	A	A	A	A

Catatan : A = Acceptable ; AR = ALARP ; NA = Not Acceptable

The results of an analysis of the fire scenario is, additional mitigation measures no needed that it is certain that the frequency of the scenario has not changed.

Risks received with explosion scenario based on the number of human victims affected by the accident. The following assessment is obtained based on the results of the analysis:

Table 9. Risk analysis for explosion scenario

Anual cumulative frequency		Consequence category				
Class	Range	5	4	3	2	1
1	$>10^{-1}$	AR	NA	NA	NA	NA
2	$10^{-1} - 10^{-2}$	AR	AR	NA	NA	NA
3	$10^{-2} - 10^{-3}$	A	AR	AR	NA	NA
4	$10^{-3} - 10^{-4}$	A	A	AR	AR	NA
5	$10^{-4} - 10^{-5}$	A	A	A	AR	AR
6	$10^{-5} - 10^{-6}$	A	A	A	A	AR
7	$<10^{-6}$	A	A	A	A	A

Catatan : A = Acceptable ; AR = ALARP ; NA = Not Acceptable

Risk analysis results from explosive scenarios is acceptable. Additional mitigation measures not needed that it is certain that the frequency of the scenario has not changed.

5. Conclusion

The probability analysis results of an ORF gas pipeline leak are 3.06 events / 100000 years or class 5 if referring to the NFPA 59A frequency band. The results of the analysis of the consequences of ORF gas pipe leakage by modeling gas dispersion, fire and explosion using ALOHA software are Consequence of gas dispersion scenarios is that it can cause respiratory problems but does not cause fatality so that for probability when referring to the consequence table NFPA 59A classified as category. Consequences of fire scenarios, can cause burns to fatality so that for probability if referring to the consequence table NFPA 59A 59A classified as category. The consequences of an explosion scenario can cause building glass to break so that people can cause damage, because probability when referring to the consequence table NFPA 59A 59A classified as category. The results of the analysis of the risk level for ORF gas pipe leakage are analysis of the risk level of a gas dispersion scenario is acceptable risk, Analysis of the risk level of a fire scenario is acceptable risk. Analysis of the risk level of an explosion scenario is acceptable risk. The risk levels of the three scenarios, gas dispersion, fire and explosion are all acceptable so that additional mitigation is not needed other than what is currently available. In order to conduct a probability analysis and risk consequences periodically to ensure the level of risk remains at a acceptable level (acceptable). Ensure that all existing mitigation or risk controls are carried out properly. Ensure that all risk mitigation has been communicated and socialized with the responsible person and related parties. Conduct trials and exercises in handling emergencies on a regular basis, according to the potential risks that have been evaluated.

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