

Prevent Major Incident Installation Using Consequence Based Method

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Abstract—The aim of this paper is to identify the consequences of the LPG explosion towards the surrounding area and to compare the land-use restriction imposed by different countries with the result obtained. The consequences were calculated by using the static model of BLEVE and the overpressure. Askolani LPG storage facilities has been selected to perform a case study. The result obtained from the thermal radiation and overpressure calculation has allowed a comparison of different LUP criteria and have been used to evaluate the consequence of the explosion. From the comparison, it can be seen that the threshold limit value obtained from the ALOHA US EPA and the threshold limit value of French Guideline is much similar compared to the other two guideline. Thus, it is the best way to address the safety distance and lethal effect resulting from the studied scenario.

Keywords— BLEVE, Consequence Based Method, Land Use Planning, LPG

I. INTRODUCTION

Major accident is defined as an incident of a major emission, fire or explosion due to uncontrolled development in the industrial activity which leads to a serious danger to workers, the public or the environment either by immediate or delayed, inside or outside the establishment involving one or more hazardous substances [1]. Major Accident Hazard (MAH) installation is defined as isolated storage and industrial activity at a site handling and transporting of hazardous chemical equal or in excess of the threshold quantities [2]. The concern arises with major accident installation is the MAH facilities were built in the area of high population density [3]. Due to this establishment it creates a high potential risk under certain scenario as it kept on revolving until it exceeds its limit [4].

Based on previous chemical industry accident, such as Bhopal accident (2nd December 1984) and Mexico City accident (19th November 1984), it portrays the severity of the after effect of a chemical accident which affect an area with high population density. Through this event, some of the European countries start showing their concern and awareness by taking into consideration the importance of Land-Use Planning (LUP) in their legislatures. This effort was made in order to reduce the risk of Major Accident Hazard (MAH) for a fixed installation. Moreover, some prevailed legislative already enforced to set apart certain chemical industry facilities to be built away from the high population density area also separating the industrial zone with other land uses [5].

In order to reduce potential risk, the like-hood and consequences of the risk need to be considered in defining the risk [6]. Therefore, risk assessment plays an important part in order to develop LUP policy. Risk assessment can be defined as the process to determine the level of risk created by the potential hazard sources found within the Major Hazard Installation (MHI) by qualitative and/or

quantitative [5] whereas risk management is defined as the procedure develop to control the risk [6]. In LUP the purposed of risk assessment is to provide necessary information for a several decisions which among it was related to the LUP. However, the result of risk assessment will differ based on the method used [7]. There are several approaches that can be used for risk assessment which are consequences-based approach, risk-based approach, generic safety approach and hybrid approach. This paper will be limited to consequences based method. The consequence calculation refers strictly to the fireball effect of the Liquefied Petroleum Gases (LPG) explosion of 10 to 130 cylindrical LPG tong. In which by calculating the thermal radiation effect and overpressure effect. Generally, for consequence-based approach, it uses the consequences of several possible event scenarios that could occur to the installation. Furthermore, it illustrates the affected area in term of lethal effect and severity of injuries emerging from the scenario case study [5]. However the method of setting the risk varies among countries due to different cultural and historical background and administrative framework. Thus the aim of this paper is to identify the consequences of the LPG explosion towards the surrounding area and to compare the land-use restriction imposed by different countries with the result obtained.

II. METHODOLOGY

For the determination of the Land Use Planning impact of the Liquefied Petroleum Gases (LPG) activities towards surrounding, there were several steps that will be used. Firstly the selection of existing Land Use Planning guideline follow by the identification of the consequences and the vulnerability of the LPG incident by using Consequences Based Method (CBM). Next is to study the impact of the LPG incident on the selected LPG facilities using CBM. Lastly was to compare the result, CBM obtained from the calculation with the selected existing guideline.

1. Selection of existing LUP guideline.

Since this study was done on LPG incident, the possible incident that could occur related to LPG is the explosion of LPG. In which the explosion of LPG could lead to the scenario of Boiling Liquid Expanding Vapor Explosion (BLEVE) [8]. Several existing guideline has already specified the threshold limit value in consideration of BLEVE incident. Thus, from the existing guideline selected were listed below [9] [10]:

Existing Consequence based method	French Guideline	Italian Guideline	British (UK) guideline
Thermal radiation effect	High lethality: 8 kW/m ²	High Lethality: 12.5 kW/m ²	First degree burns: 700 (kW/m ²) ^{4/3} s
	Beginning lethality: 5 kW/m ²	Beginning Lethality: 7 kW/m ²	Second degree burns: 900 -1300 (kW/m ²) ^{4/3} s
	Irreversible effect: 3	Irreversible effect: 5	Third degree burn : 2000-3000

	kW/m ²	kW/m ²	(kW/m ²) ^{4/3} s
		Reversible effect : 3 kW/m ²	
Overpressure effect	High lethality : 200 mbar	High lethality : 300 mbar	20% fatality for personnel inside, 0% fatality for personnel in the open: 210mbar
	Beginning lethality : 140 mbar	Beginning lethality : 140 mbar	50% fatality for personnel inside and 15% fatality for personnel in open: 350mbar
	Irreversible effect : 50 mbar	Irreversible effect : 70 mbar	100% fatality inside or in unprotected structure: 700 mbar
	Indirect effect : 20 mbar	Reversible effect : 30 mbar	
Effect on humans			Threshold for eardrum perforation : 200-500 mbar
			1% glass breakage : 17 mbar
			90% glass breakage: 62 mbar

Table 1: Selected Existing LUP criteria

2. Identification of Consequences and Vulnerability of LPG explosion

a) Consequence Analysis

The consequence analysis was done in identifying the consequence of the LPG explosion towards its surroundings. The analysis was done in term of:

i. Thermal Radiation Effect

The thermal radiation effect was calculated by calculating the diameter, duration and height of the BLEVE fireball by using several models. The diameter and duration of the fireball are calculated by using the equation below [11]:

$$D = aM^b$$

Where D: diameter of the fireball (m), M: mass of fireball (kg), a and b is a constant value [11].

$$t = cM^e$$

Where t: duration of fireball (s), c and e are a constant value. Roberts model was being used in order to determine the constant value for estimating fireball diameter and duration [12].

Model	a	b	c	e
Moorhouse	5.80	0.333	0.450	0.333

Table 2: Moorhouse Model constant Value

Whereas the height of fireball was calculated when the fireball reached ¾ of the diameter by using the following equation [11]:

$$H = 0.75D_{max}$$

Where H: height of fireball (m), D_{max}: Maximum diameter of fireball (m).

i. Static Model

The static model was used to determine the heat radiation from the BLEVE by calculating the heat flux using equation below [11]:

$$E = \frac{RMH_c}{\pi \cdot t_{BLEVE} \cdot D_{max}^2}$$

Where E: Radiative Emissive flux (W/m²), R: radiative fraction of heat combustion, H_c: heat of combustion (kJ/kg).

According to Hymes (1983) the value of R can be assumed as:

- 0.4 for fireball from vessels bursting at/or above the relief set pressure.

F₂₁ can be calculated by using the following equation as below [11]:

$$F_{21} = \frac{D_{max}^2}{4r^2}$$

Where F₂₁: view factor (dimensionless)

The determination of thermal heat flux receives by receptor/black body was calculated by using the equation below [11]:

$$E_r = \tau_a E F_{21}$$

Where E_r: emissive radiative flux received by a receptor (W/m²), E: surface emitted radiation flux (W/m²) τ_a : atmospheric transmissivity (dimensionless) in which the value of τ_a varies from the water vapor content based on temperature and atmospheric humidity. Thus the value of τ_a was estimated from the following equation referring to the value of P_wl obtained [13]:

$$\tau = 1.53(P_{w,l})^{-0.01}, \text{ for } P_{w,l} < 10^4 \text{ Nm}^{-1}$$

$$\tau = 2.02(P_{w,l})^{-0.09}, \text{ for } 10^4 \leq P_{w,l} < 10^5 \text{ Nm}^{-1}$$

$$\tau = 2.85(P_{w,l})^{-0.12}, \text{ for } P_{w,l} > 10^5 \text{ Nm}^{-1}$$

$$P_w = P_{wa} \frac{H_R}{100}$$

$$\ln P_w = 23.18986 - \frac{3816.42}{(T - 46.13)}$$

Where P_w: water partial pressure (N/m²)

ii. Overpressure

TNT Equivalency

The overpressure was determined by using the TNT Equivalency Method. This method is used to determine the maximum overpressure from Unconfined Vapor Cloud Explosion (UVCE) event in which TNT equivalence assumes that the exploding fuel mass behave like exploding TNT on an equivalent energy basis. The mass of TNT was calculated by using the following equation [13]:

$$m_{TNT} = \frac{\eta m \Delta H_{c(gas)}}{E_{(TNT)}}$$

Where m_{TNT}: equivalent mass of TNT (kg), m: mass of flammable gas in the cloud, η : empirical explosion efficiency (dimensionless). ΔH_c (gas): energy of explosion of the flammable gas (J/kg), E_{TNT}: energy of explosion of TNT. The typical value of E_{TNT} = 1120 Cal/g = 4686 kJ/kg.

The TNT equivalent mass also was used to calculate the equivalent effects of explosions occurring in the distance from the ground-zero point of explosion by using the following equation [14]:

$$Z_e = \frac{r}{m_{TNT}^{\frac{1}{3}}}$$

Where Z_e value is related to scaled overpressure, ps. The scaled overpressure was calculated by using the following equation [13]:

$$P^s = \frac{P^0}{P_a} \left[1 + \left(\frac{Z_e}{4.5} \right)^2 \right]^{-1}$$

$$P^0 (\text{kPa}) = P_a \cdot \frac{1616 \left[1 + \left(\frac{Z_e}{4.5} \right)^2 \right]}{\sqrt{1 + \left(\frac{Z_e}{0.048} \right)^2} \sqrt{1 + \left(\frac{Z_e}{0.32} \right)^2} \sqrt{1 + \left(\frac{Z_e}{1.35} \right)^2}}$$

b) Vulnerability Analysis

i. Effect of overpressure on Humans and Structures

The effect of overpressure on humans and the structure was determined by finding the probit. The probit variable can be

computed from [15]:

$$Y = k_1 + k_2 \ln V$$

The probit correlation varies depends on the exposure.

Type of injury/ damage from the explosion	Causative Variable, V	Probit Parameter	
		k ₁	k ₂
Eardrum Rupture	p ⁰	-15.6	1.93
Glass Breakage	p ⁰	-18.1	2.79

Table 3: The constant value for Probit Correlation

ii. Effects of Thermal Radiation on Human and Construction

The time required for pain with reasonable accuracy can be calculated by using the following equations [16]:

$$t_p = \left[\frac{35}{Q} \right]^{1.33}$$

Where t_p: time required for pain (sec)

The probability of fatality due to incident of thermal radiation can be calculate by using the following equation [15]:

$$Y = -14.9 + 2.56 \ln(Q^4 t)$$

Whereas the probit equation for non-fatal injury were as below[16]:

- First Degree burn

$$Y = -39.83 + 3.02 \ln(Q^4 t)$$

- Second Degree Burn

$$Y = -43.14 + 3.02 \ln(Q^4 t)$$

3. Selection of existing LPG facilities to conduct the impact of the LPG explosion by using Consequences based method:

Askolani Bakri Sdn Bhd is a company that stored large amounts of LPG cylindrical tank. Therefore, it was chosen as the LPG facility to undergo the case study of LPG explosion. The detail location was as below:

Name of the company: ASKOLANI BAKRI SDN BHD

Address: Kampung Muhibbah, 58200 Puchong, Selangor

Coordinate: 3°03'49.10"N; 101°39'10.19"E with the elevation of 20 m.

Building at surrounding:

- North: Resident Area at (210 to 270) meter from the facilities
- West: Factory Building at (100 to 250) meter from the facilities
- East: Forest at 255 meter and Resident Area at (743 to 1000) meter from the facilities
- South: Resident Area at (374 to 620) meter from the facilities

Once step 1, 2 and 3 were completed the all the data will be used in comparing the consequences based method data in step 2 with the existing guideline in step 1.

III. RESULTS AND DISCUSSION

1. Case Study of LPG explosion at Askolani Bakri LPG Storage Facilities Aloha US EPA software & MARPLOT Software

From the ALOHA USA EPA and Marplot software it can predict the threat zone of LPG explosion. However the threat zone obtained only applicable for the explosion of one 14 kg LPG cylindrical tong whereas the data that have been calculation were varies from 10 tong to 130 tong of 14 kg LPG cylindrical tong explosion.

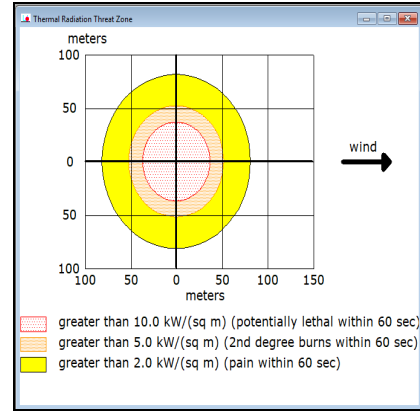


Figure 1: The threat zone plotted in the Aloha US EPA software

Based on the data obtained from the ALOHA US EPA it stated that if the thermal radiation value more than 10.0kW/m² thus it is potentially lethal within 60 sec whereas at thermal radiation greater than 5.0 kW/m² but lower than 10.0kW/m² it consider as 2nd degree burn within 60 sec and lastly for thermal radiation greater than 2.0 kW/m² but lower than 5.0 kW/m² consider pain within 60 sec.

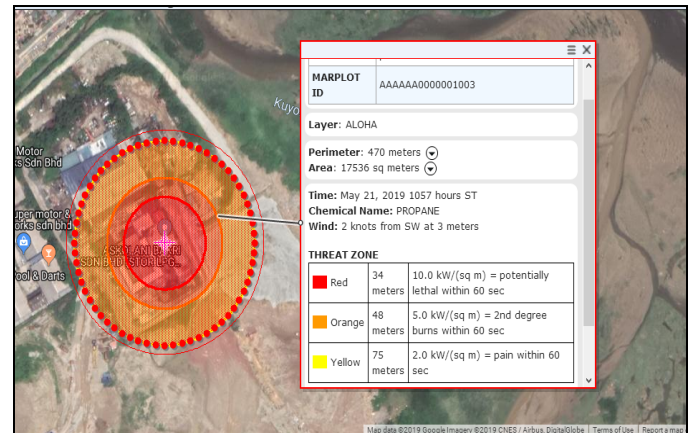


Figure 2: The data plotted in the MARPLOT software based on ALOHA US EPA threat zone

The threat zone obtained from the ALOHA USA EPA software was projected to the map of Askolani LPG storage facilities in order to determine the area effected. Based on the projection it can be seen that at 34 meter it is consider as red zone with the thermal radiation of 10.0kW/m² whereas at 48 meter it is consider as yellow zone at thermal radiation of 5.0 kW/m². Lastly the yellow zone is at 75 meter for thermal radiation of greater than 2.0 kW/m². From result of calculation the value of thermal radiation from a single 14 kg cylindrical a LPG explosion it radiates 5.0 kW/m² at distance of 93m, the thermal radiation indicates that it is in the orange zone. However if we look from the distance the value obtained from the manual calculation are slightly bigger than the distance obtained from the MARPLOT. This is due to the different models and set point was used in calculating the thermal radiation as from the manual calculation, the thermal radiation area calculated from by using the Moorhouse model in which might affect the thermal radiation value. Nevertheless both result shows that none of the surrounding area was affected by the explosion except the facilities building itself.

2. Comparison of calculated data with the selected existing Consequences Based Method

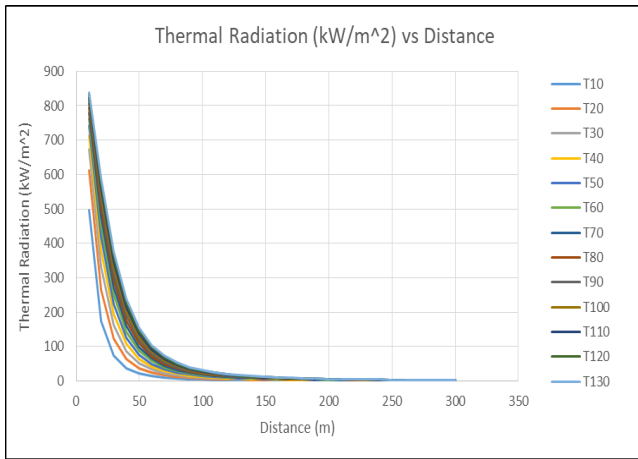


Figure 3: Thermal Radiation (kW/m²) vs Distance (m)

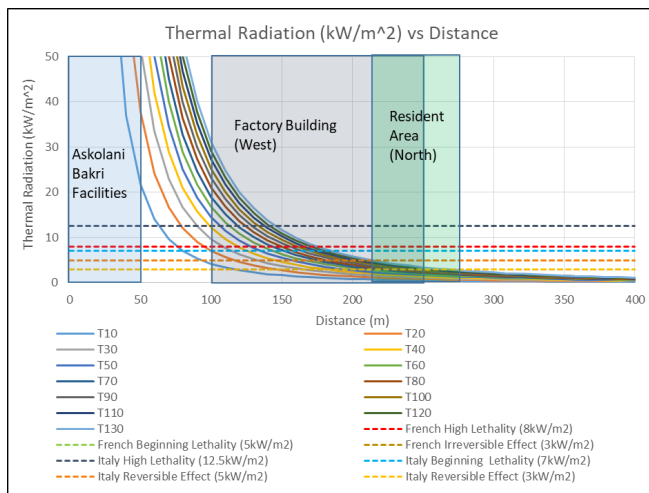


Figure 4: Parts of Thermal Radiation (kW/m²) vs Distance (m)

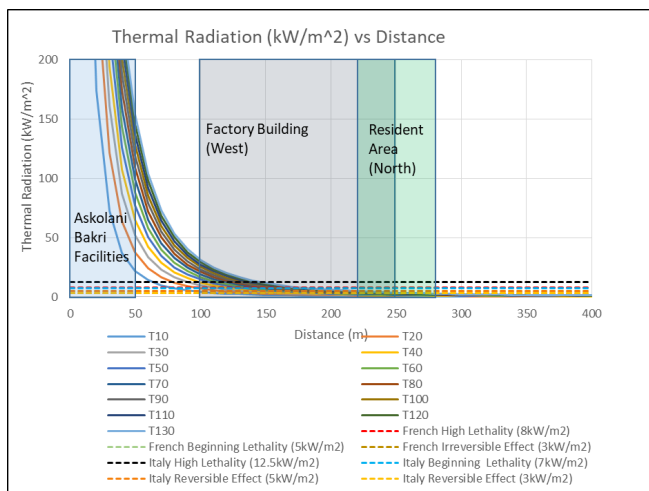


Figure 5: Parts of Thermal Radiation (kW/m²) vs Distance (m)

Figure 3 show the overall thermal radiation for the explosion of 10 to 130 tong of cylindrical LPG at distance 0 to 300 meter. Comparing the obtained data in Figure 4 and Figure 5 with the French and Italian LUP criteria most of the thermal radiation lead to high lethality as the value obtained from the calculation part exceed 8 kW/m² (French LUP) and 12.5 kW/m² (Italian LUP). Based from the case study of Askolani Bakri, colored area in Figure 4 and Figure 5 indicate the area affected by the thermal radiation. The affect facilities area are, the area at distance 100 to 150 meter and 200 to 250 meter. This area are happen to be at the west side (factory) and the north side (resident area) located from the Askolani Bakri. However this thermal radiation toward physical effect kept decreasing as the distance increase.

Nevertheless the value of thermal radiation stated by French is little more restrictive compare with Italian as it was set based on analysis of past accident and possible events. Plus the value that set by the French guideline is being used to determine the protected zone around the installation.

Furthermore by comparing the threshold limit value for the three guideline with the data obtained in the ALOHA US EPA, it shows that the French Guideline threshold value does not show any significant changes compare to the other two guideline.

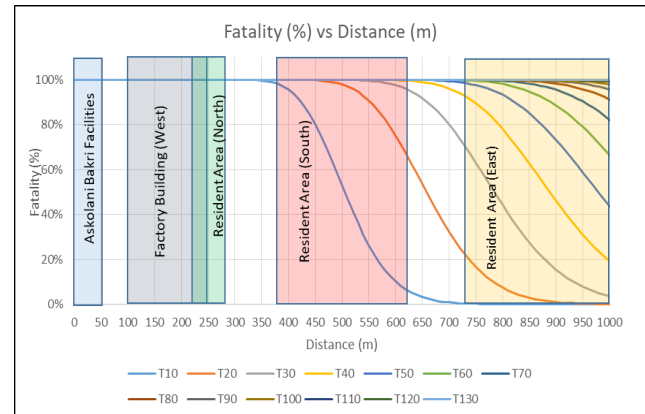


Figure 6: Fatality (%) vs Distance (m)

From Figure 6, based on the fatality probit against the distance, the affected area increase as the number of tong explode increase. For the explosion of 10 tong, it took 600 meter in order to reach 10% fatality whereas for 130 tong of LPG even at 1000 meter it still remain 100% fatality. Based on the case study of Askolani Bakri LPG explosion, all the building listed in the methodology part at south (resident area at 374 meter), west (factory building at 100 meter), east (resident area at 743 meter) and north (resident area at 210 meter) including the facilities area will be affected by fatality.

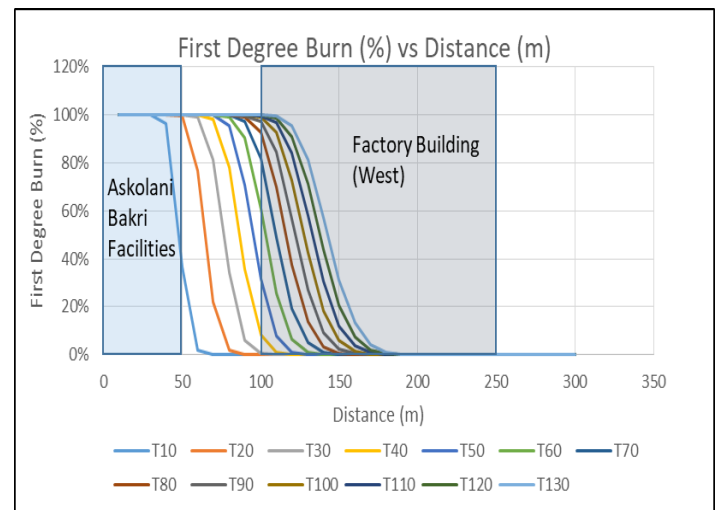


Figure 7: First Degree Burn (%) vs Distance (m)

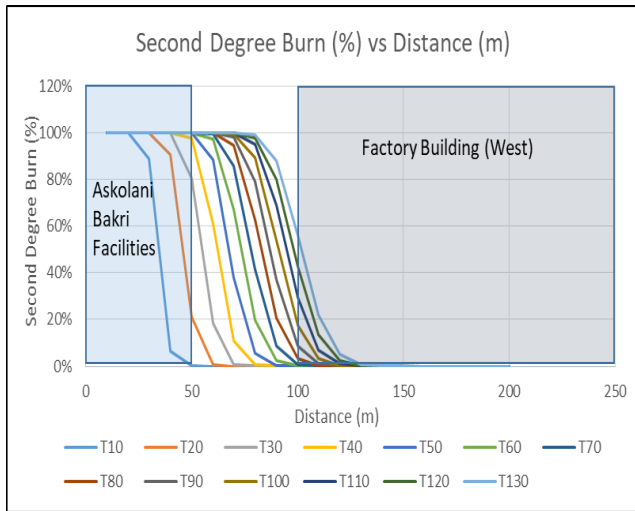


Figure 8: Second degree burn (%) vs Distance (m)

For British LUP criteria it related the thermal radiation with the degree of burn instead of lethality. In Table 1, at $700(\text{kW}/\text{m}^2)^{4/3}$ s it is consider as first degree burn follow by $900-1300(\text{kW}/\text{m}^2)^{4/3}$ s for second degree burn and $2000-3000(\text{kW}/\text{m}^2)^{4/3}$ s for third degree burn. However this threshold value will differ depending on the time of fireball in second. From manual calculation, the duration already being consider in the calculation. Thus from the data obtained it shows that the degree of burn varies depending on the number of tong exploded. Nevertheless from Figure 7 it can be seen that the affected area for first degree burn from the explosion of 10 tong to 130 tong were from 0 to 180 meter. Whereas for second degree burn in Figure 8 it show that the affected area were in the range 0 to 130 meter. Therefore, from the case study of Askolani Bakri LPG first degree burn and second degree burn it affect the area at the west site (factory at 100 meter) and the facilities building itself.

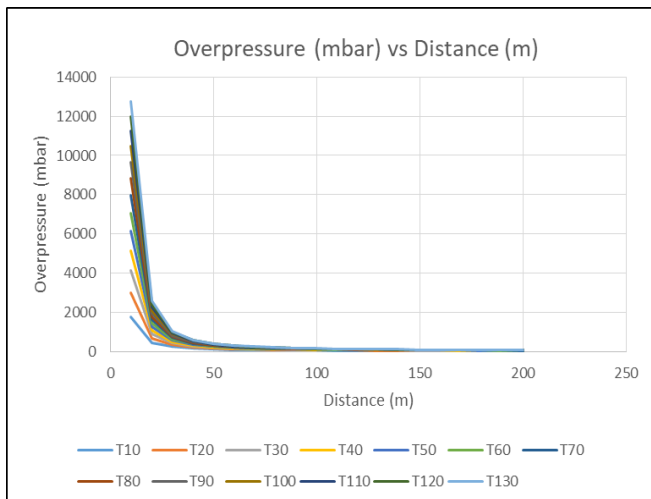


Figure 9: Overpressure (mbar) vs Distance (m)

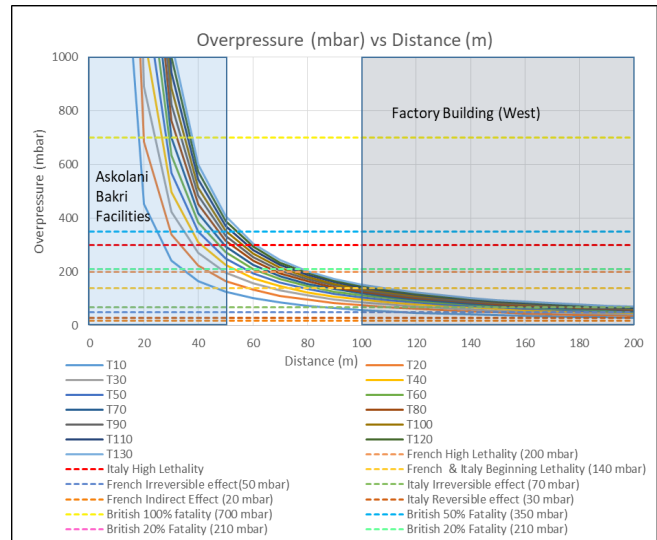


Figure 10: Parts of Overpressure (mbar) vs Distance (m)

In French guideline the overpressure for high lethality are 200 mbar follow by 140 mbar for beginning of lethality, 50 mbar for irreversible effect and 20 mbar for indirect effect. Thus in Askolani Bakri case study at distance 0 to 50 meter are in the range for high lethality, 50 meter as beginning lethality and 50 to 80 meter as irreversible effect and 80 to 120 meter for indirect effect. Therefore in the case study it only affect the factory building at the west of facility apart from its own building.

Differ with Italian guideline it set the overpressure of 140 mbar as high lethality, 70 mbar as irreversible affect and 30 mbar for reversible affect. Thus in Askolani Bakri case study at distance 0 to 50 meter are in the range for high lethality, 50 to 70 meter as irreversible effect and 70 to 120 meter as reversible effect. Similar with the French guideline it only affect the factory building at the west of the LPG facilities.

For British it set that 20% fatality for personnel inside and 0% fatality for personnel in the open at 210mbar, 50% fatality for personnel inside and 15% fatality for personnel in open at 350mbar and 100% fatality inside or in unprotected structure for 700 mbar. Therefore the distance that reach 700 mbar are at 0 to 10 meter followed by 10 to 30 meter for 310 mbar and 30 to 40 for 210 mbar. Thus in the case study, none of the area at the surrounding are consider affected based on British criteria as there are no building at the range listed apart from its own building.

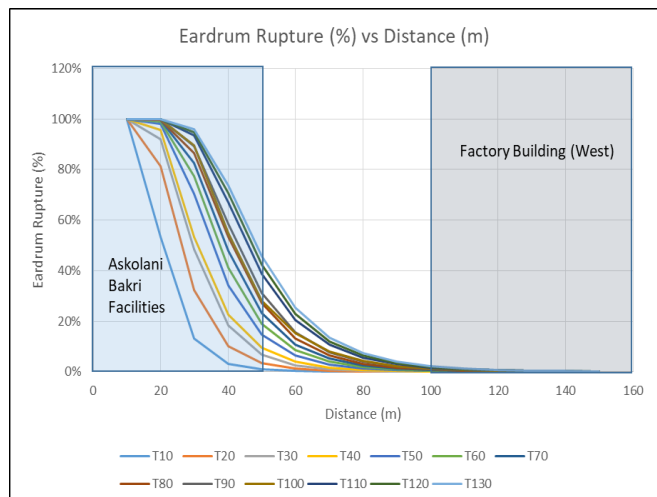


Figure 11: Eardrum Rupture (%) vs Distance (m)

Apart from that British LUP it also set the threshold for eardrum rupture and glass breakage depending on the overpressure. As stated in Table 1 the threshold for eardrum perforation are at 200-

500 mbar. Based on data obtained for overpressure the range for eardrum perforation are at 0 to 80 meter tally with the probit obtained for the eardrum perforation. If this result are reflected in the case study, it can be conclude that only the facilities area will affected.

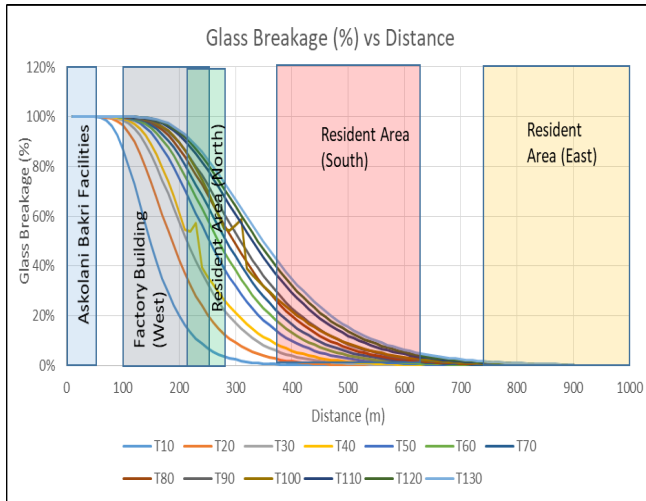


Figure 12: Glass Breakage (%) vs Distance (m)

For glass breakage the threshold value are 17 mbar for 1% glass break and 62 mbar for 90% glass break. From the overpressure result 0 to 230 meter indicates 100% glass breakage as the overpressure value obtained only reach 62mbars at the distance of 230 meter. For the explosion of 130 tong of LPG it takes 800 meter to reach 1% glass breakage which slightly different from the distance obtained from the probit calculation of glass breakage as it takes 880 meter to obtain 1% glass breakage. By reflecting this value in the case study, it shows that all the area at the south (resident area at 374 meter), west (factory building at 100 meter), east (resident area at 743 meter) and north (resident area at 210 meter) will be affected by glass breakage effect.

IV. CONCLUSION

The paper present a case study of the LPG facility explosion by comparative consequence analysis using three existing criteria which developed an efficient LUP methodology. Each criteria give different result in the extension of land use limitation in the priorities of hazardous actions. Based from the listed threshold limit value for the three guideline, the French Threshold limit is a bit restrictive compared to the other two guideline due to the different approach of addressing the risk. Furthermore, by comparing the threshold limit value obtained from the ALOHA US EPA with the threshold limit value of French Guideline the value is much similar compared to the other two guideline. Thus, it is the best way to address the safety distance and lethal effect resulting from the studied scenario. Apart from that, thru the comparison of data obtained with the existing guideline, it can be seen that from the French and Italian guideline, it show that LPG explosion will lead to fatality and lethality. Whereas British guideline show that the LPG explosion will lead to the first degree burn, second degree burns, glass breakage and overpressure effect toward the surrounding of case study location.

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