Hazards Analysis of LPG Storage Installation in Universiti Putra Malaysia: A Preliminary Study

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ABSTRACT

A preliminary risk analysis on the impact of LPG storage explosion to the community in the Faculty of Engineering, Universiti Putra Malaysia (UPM) is studied. This paper is aimed to evaluate the physical effects of the release of hazardous substances or energy following various possible accidental events. This paper focuses on the final events that are: confined explosion fireball/ boiling liquid expanding vapour explosion (BLEVE), jet-fire and pool-fire. Several physical models including Trinitrotoluene (TNT) model are used to evaluate each possible accident and the calculated results of the affected area and distance are also shown.

Keywords : *LPG, confined explosion, BLEVE, jet-fire, pool-fire, TNT model, GIS*

INTRODUCTION

The rapid growth in the use of hazardous chemicals in the industry has brought significant increase of risk to a number of people, both workers and public, whose life could be endangered at any one time by accident involving these chemicals [1]. Risk analysis is a discipline, which has constantly been gaining interest almost three decades among the process industry community. Especially concerning to the major industrial accidents that occurred during the years, such as Flixborough (1974), Seveso (1976), Mexico City (1984), Texas (1989), Kuwait (2000), Lincolnshire (2001) and Shandong, (2003), contributed to that interest. Malaysia also had experience in some major accidents, such as the explosion and fire of at the firecracker plant (Bright Sparkle), the explosion of ship-tanker loaded with hydrocarbon at Port Klang Shell Depot and recently the explosion of fertilizer's warehouse at Port Klang, Malaysia [2].

Storage and transportation of dangerous substances have defined the set of risk sources, which are located on territory, called impact area. Release of chemical due to accident could be severe and poses an immediate effect to workers on-site and communities off-site as well as the potential to adversely affect the environment. Liquefied petroleum gas (LPG) is a very important fuel and chemical feed stock. However, it also causes major fires and explosions. For bulk storage and bottling of liquefied petroleum gas (LPG), there are 11 major hazards installations (MHI) and 150 non-major hazard installations (NMHI) as categorized under Control of Industrial Major Accident Hazards (Amendment) Regulations, 1990 (CIMAH) [2]. These incidents can be unconfined vapour cloud explosions, confined explosions, boiling liquid expanding vapour explosions and fires. The causes of these losses have involved chemical accidents, overfilling of containers, and loading and sampling operations. Several physical models can be used to calculate and to predict the physical effects of explosion and fire from LPG accidents. Furthermore, the area affected can also able be predicted.

A preliminary risk analysis on the impact of LPG storage explosion to the community in the Faculty of Engineering, Universiti Putra Malaysia (UPM) is studied. The Faculty of Engineering of Universiti Putra Malaysia is located at the Serdang Campus, some 22 kilometres to the south of Kuala Lumpur, currently as one of the largest faculties at UPM with student enrolment of 3000. The LPG storage tank is to be installed as part of the second phase development project of faculty facilities. The storage tank is in cylindrical shape, with capacity of 120 tones. The dimensions of the vessel are 30 m in length and 4 m in height.

Geographical Information System (GIS) is used as a tool to provide geographical information of the potential affected areas in order to evaluate the consequences or impact of the disaster. The functionality of GIS enables the integrated model to handle the data management, computational aspects and the integrated needs as emphasised in the hazards approach. The role of the GIS, therefore, is to allow a modeller to visualize development changes to the landscape and to produce resultant input values for the individual models and create a map of a target source. The affected area in vicinity of the LPG storage tank in UPM was identified by using ArcView 8.3 software. ArcView 8.3 can be use easily to create maps and to add the data to them. Using ArcView software's powerful visualization tools, one can access records from existing databases and display them on maps.

RISK ANALYSIS IN LPG INSTALLATION

The scope of this paper is to evaluate the physical effects of the release of hazardous substances or energy following the possible accidental events. The evaluation of each release is represented using cause-consequence diagrams, Event Tree, that starting from the initial accident event eventually build all the plausible scenarios. Figure 1 shows the event tree for LPG released and the probabilities for the various possible of the events [3]. This paper focuses on the final events that are: vapour cloud explosion (VCE), boiling liquid expanding vapour explosion (BLEVE) and fire.

Explosion Hazards

The main hazard from explosion is the blast wave. A blast wave is the result of an explosion in air that accompanied by a very rapid rise in pressure. Pressure effects are usually limited in magnitude and are thus of interest mainly for prediction of domino effects on adjacent vessels and equipment rather than for harm to neighbouring communities. The blast effects can be estimated from the TNT equivalence method. Table A1 presents criteria for assessing the likelihood of eardrum rupture occurring as a result of exposure to blast wave overpressures [4]. The pressure effects on humans due to blast waves [5] are presented in Table A2. Pressure effects are usually limited to a small area and the effect of pressure on the environment is therefore seldom discussed. However, the same discussion as for humans is also valid, for both the general environment and animals; namely any adverse effects or injuries are more dependent on them being hit by a flying object. Table A3 describes the types of damage that may occur to various construction types as a result of exposure to various levels of peak side-on overpressure. As illustrated, significant damage is expected for even small overpressure [5].

A confined explosion occurs in a confined space, such as a vessel or a building. A confined explosion is a result of a rapid chemical reaction, which is constrained within vessels and buildings. Dust explosions and vapour explosions within low strength containers are one major category of confined explosion [3]. A basic distinction between confined explosions and unconfined explosions is confined explosions are those which occur within some sort of containment. Often the explosion is in a vessel or piping, but explosions in buildings also come within this category. Explosions, which occur in the open air, are unconfined explosions.

The calculation models of peak overpressure are primarily based on broad approaches. The simplest model is the TNT equivalence method. TNT model is based on the assumption of equivalence between the flammable material and TNT, factored by an explosion yield term [6]. TNT model is based on the assumption of equivalence between the flammable material and TNT. An equivalence mass of TNT is calculated using the following equation [7]:

$$m_{TNT} = \eta \, M \, \Delta H_c \, / \, E_{TNT} \tag{1}$$

The distance to a given overpressure is calculated from the equation [8]:

$$r = 0.367 \; x \; m_{TNT}^{1/3} \; exp$$

$$\left[3.531 - 0.7241 \; ln(p_o) + 0.0398(1np_o)^2 \right] \tag{2}$$

Table 1: Peak overpressure vs. distance for blast wave from an explosion

r(m)	p^o(kPa)
100	94.22
200	27.61
300	14.64
400	9.60
500	7.01

The TNT equivalence predicts peak overpressure with distance. It should be noted that the pressure depends strongly on the distance between the place of the explosion and the structure. The consequence is that explosion of the same explosive charge can cause very different overpressures depending on the location of the explosive charge.

Boiling Liquid Expanding Vapour Explosion (BLEVE)

Boiling Liquid Expanding Vapour Explosion (BLEVE) occurs when there is a sudden loss of containment of a pressure vessel containing a superheated liquid or liquefied gas. A BLEVE is a sudden release of a large mass of pressurized superheated liquid to the atmosphere. Formulas to estimate the BLEVE physical parameters are as follow [6]:

$$D_{max} = 6.48M^{0.325} \tag{3}$$

$$t_{BLEVE} = 0.825M^{0.26} \tag{4}$$

$$H_{BLEVE} = 0.75 \, D_{max} \tag{5}$$

$$D_{initial} = 1.3 \, D_{max} \tag{6}$$

Table 2: The resuts of BLEVE physical parameters

D_{max}(m)	t_{BLEVE}(s)	H_{BLEVE}(m)	$D_{initial}$(m)
289.94	17.26	217.46	376.92

A fireball is assumed to be spherical and resting on the ground. The radius is given by equation (3). The model is described in detail on the work of Roberts [9] and Fay J. and Lewis D. [10]. One of the simplest practical models for evaluating fireball hazards is the point source model. This has been used to estimate the intensity of thermal radiation from the resulting fireball. This model estimates the emissive power as a function of the combustion mass [11]. Fireball composition occurs when volatile hydrocarbons are released and rapidly ignited. In calculating the quantity of LPG participating in the fireball the complete content of the tank is generally taken into account. The radiation received by a target (for the duration of the BLEVE incident) is given by [9]:

$$Q_{t \, arg \, et} = \tau \, E \, F_{21} \tag{7}$$

Thermal radiation is absorbed and scattered by the atmospheric. Pieterson and Huerta [12], recommend a correlation formula that account for humidity:

$$\tau = 2.02 \, (P_w l)^{-0.09} \tag{8}$$

The path length, distance from flam surface to target is:
$$l = \left[H^2_{BLEVE} + r^2 \right]^{0.5} - \left[0.5D_{max} \right] \tag{9}$$

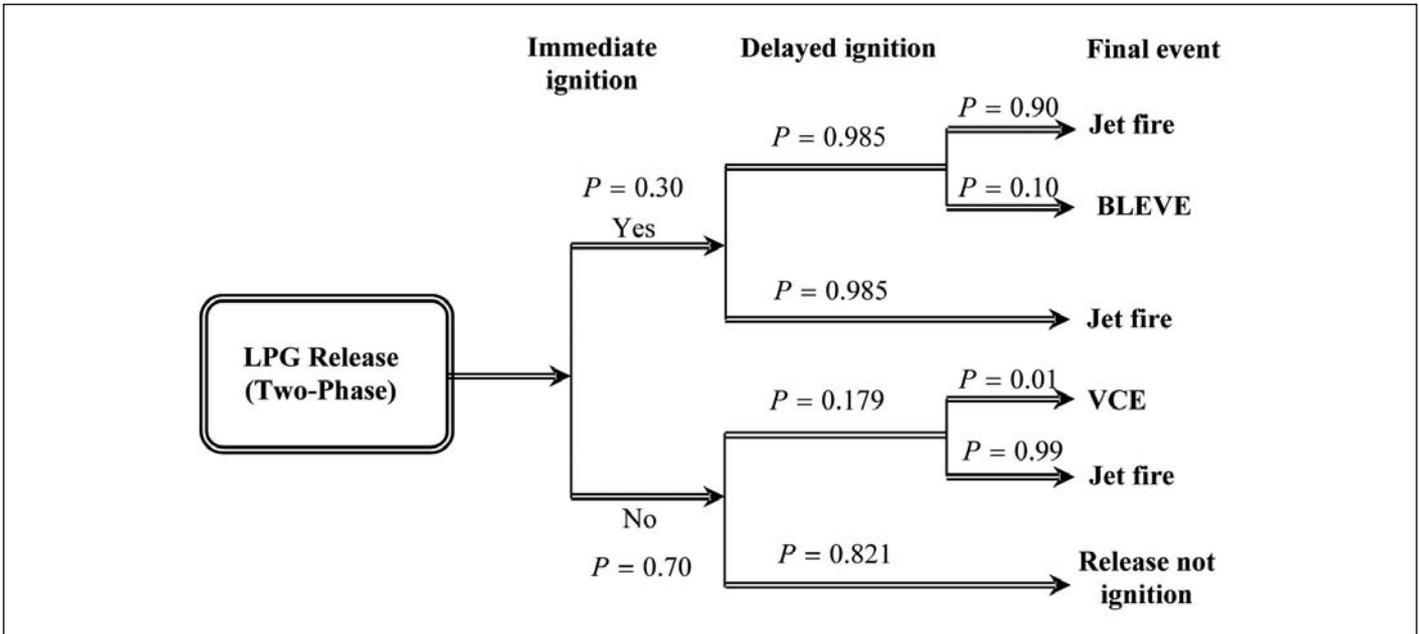Thermal radiation is usually calculated using surface emitted flux, *E*:

Figure 1: Typical Event Tree (ET) for a flashing liquid continuous release [3]

$$E = \frac{F_{rad} M \Delta H_c}{\pi (D_{max})^2 \, t_{BELVE}} \qquad (10)$$

The radiation fraction, F_{21} was given by Roberts [9] in the range of 0.25-0.4. As the effects of a BLEVE mainly relate to human injury, a geometric view factor for a sphere to the surface normal to the sphere (not the horizontal or vertical components) should be used:

$$F_{21} = \frac{D^2_{max}}{4r^2} \qquad (11)$$

BLEVE hazards are not dependent on wind speed, wind direction, or atmospheric stability [13].

Pool Fires and Jet Fires

Pool fires and jet fires are common fire types resulting from fires over pools of liquid or from pressurised release of gas and/or liquid. Pool fires are the result of spillage or leakage from tanks, pipelines, or valves. The total heat release rate of the fire can be calculated as following [14]:

$$Q_r = \zeta \, m \, \Delta H_c \, A_p \qquad (14)$$

$$m = M_\infty \left[1 - exp \, (-kD) \right] \qquad (15)$$

The mass burning rate per unit area for an infinite pool, $m\infty$ is taken as 0.099 and it is dependent on the diameter of the pool. The pool diameter is calculated as following: Around the rupture location the LPG spreads out and forms a pool $2cm$ high [15].

$$A_p = V/0.02 \qquad (16)$$

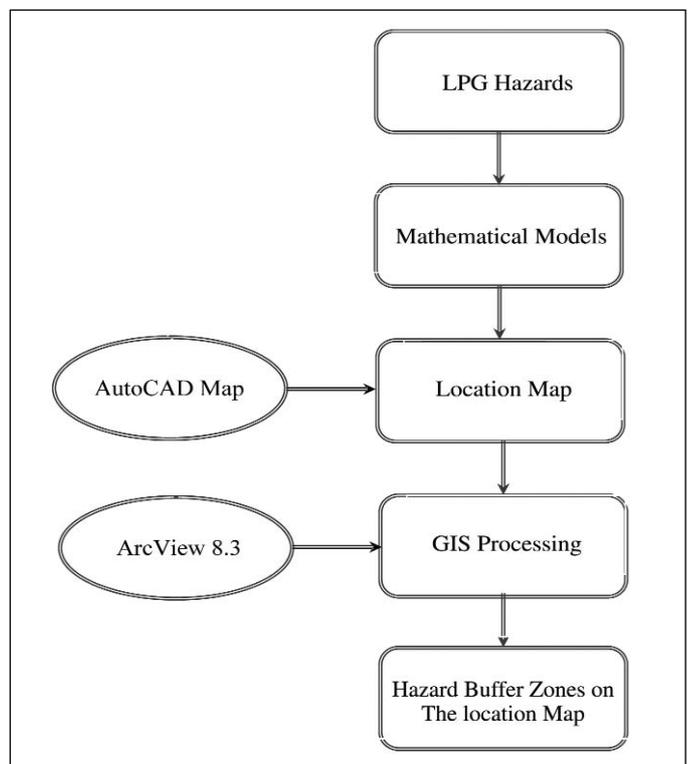$$D = \sqrt{\frac{4}{\pi} x A_p} \qquad (17)$$

Figure 2: Logic diagram for the estimating LPG hazards by using GIS

The flam high can be estimated from:

$$\frac{L_f}{D} = 42 \left(\frac{m}{\rho_a \sqrt{gD}} \right)^{0.61} \qquad (18)$$

The heat that is radiated from the pool fire is a fraction of the total amount release:

$$Q_R = \kappa Q_T \qquad (19)$$

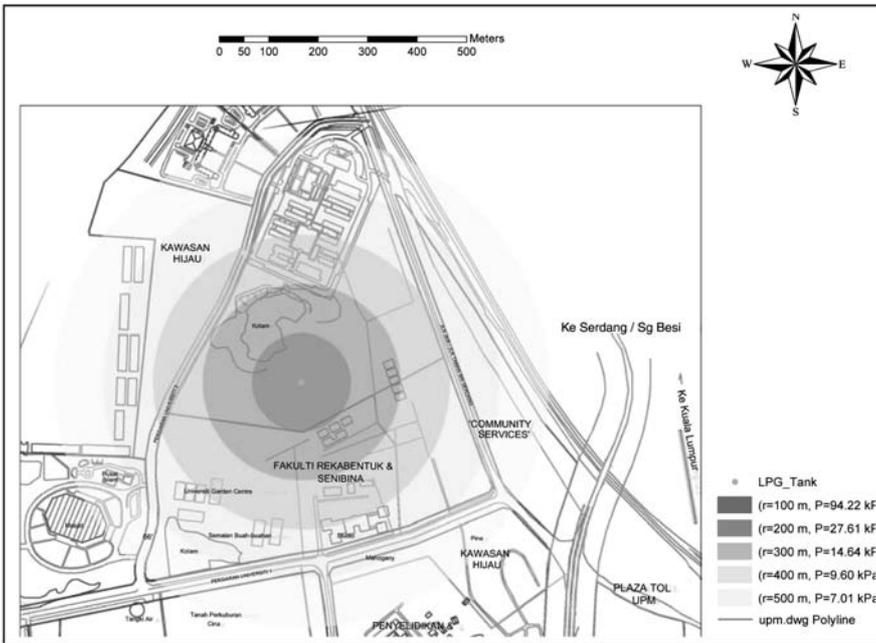where κ is the fraction of total heat emitted as radiation.
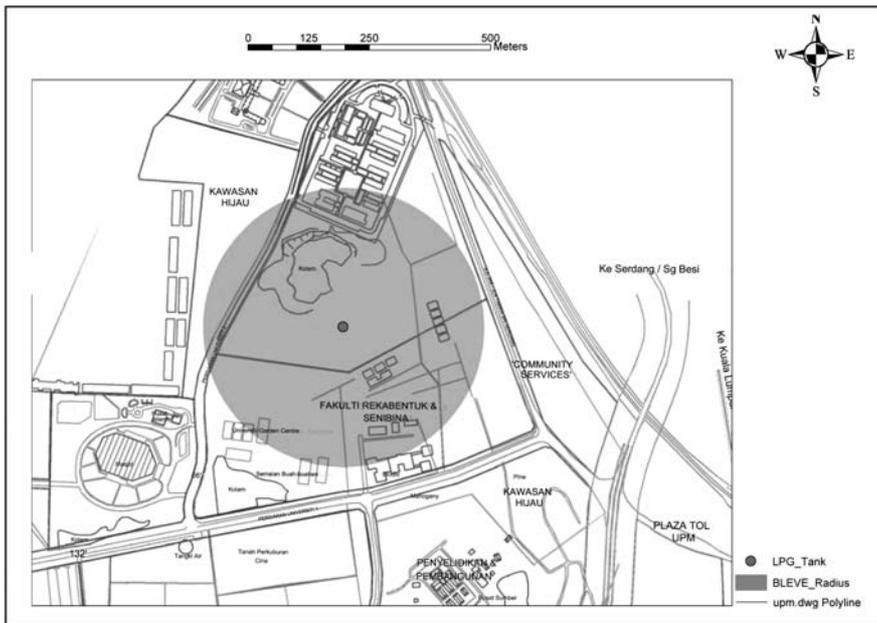
Figure 3: Peak overpressure buffer zones

Figure 4: BLEVE/Fireball radius

BUILDING THE GIS DATABASE

A substantial portion of the GIS database came from map source documents, while many other sources, such as aerial photos, tabular files, and other digital data can also be used. The map representation is only part of the GIS database, in addition, a GIS can hold scanned images (drawings, plans, photos), references to other objects, names and places and derived views from the data. Building a database consists of three major steps: identifying the geographic features, attributes, and required data layers; defining the storage parameters for each attribute; and ensuring co-ordinate registration. The collection of cartographic data can be achieved by any of these alternative procedures: extant maps through digitizing or scanning, photogrammetric procedures or terrestrial surveying measurements. AutoCAD is used as a tool in map drawing for LPG tank location and the vicinity and the scale is 1: 6,000. The procedures of estimating the hazard buffer zones are shown in Figure 2.

RESULTS AND DISCUSSION

This study aims to estimate the impacts due to installation of a LPG tank, at Faculty of Engineering, UPM. Expected consequences and the actions proposed to be taken in order to evaluate the probable effects to human and environment in the surrounding area also will be discussed. From the TNT modelling, it can be noted that the pressure depends strongly on the distance between the place of the explosion and the structure. The consequence is that the explosion of the same explosive charge can cause very different overpressures depending on the location of the explosive charge. Pressure dependsalso on the location of the explosive charge above the ground. Table 1 shows the peak overpressure results for different distances for material release. The areas affected include laboratories, classes, offices, roads, students' hostels and areas in the vicinity of Serdang Town. The resulting damage to the surrounding area is cased by a blast wave generated by an explosion event. The major effect of the hazards will be investigated in the area with radius of 500 m of LPG tank. The results in Table 1 are then referred to the Tables A1, A2 and A3 to estimate the overpressure effect on human. It is clearly seen that the major effect of overpressure generated by blast wave will affect a human being in area with radius of 200 m. It is estimated more than 10% likelihood of eardrum rupture and man may receive several fatal not only from direct exposure to the blast wave, but hit by the falling objects from the demolished structures.

Geographical data and results of hazards estimation of LPG tank of the Faculty of Engineering, UPM, are analyzed via the program of ArcView 8.3, a GIS and mapping software, in order to provide data visualization, query and analysis on the hazard of LPG tank. Figure 3 shows the peak overpressure buffer zones using ArcView 8.3 software. The buffer zones have been drowning for different peak overpressure values. It can easy classify the map to different zones depend on the pressure effects.

The major effect of thermal effect resulted from BLEVE. Thermal radiation from BLEVE can cause severe harm and damage to human and construction. The results for fireball characteristics are summarized in Table 2.

Most of the heat radiation will appear in the fireball radius. Within this radius, there will be severe damage to buildings and able to bring harm to humans. The intensity of thermal radiation from resulting fireball has been estimated from point source model. The modelling results are summarized in Table 3. In order to calculate the quantity of LPG participating in the fireball, the complete content of the tank is generally taken into account. The calculated results show that the maximum diameter of the fireball is equal to 289.94 m, indicates that all circled areas that have diameter within 289.94 m around the tank will be damaged by fireball. The maximum diameter for fireball is illustrated in Figure 4.

According to Table A4, a person who exposes to excessive radiation heat from the fires may receive fatal burns. Combustible structures maybe ignited by exposure to a radiant heatflux of 31.5 kW/m^2 or more. Therefore, it conservatively assumes that all men within the 31.5 kW/m^2 isopleths will experience high possibility of fatalities. Unprotected skin maybe severely burned if exposed to a radiant flux of 5.0 kW/m^2 for 30 second or more. In the area between 31.5 kW/m^2 and 5.0 kW/m^2 isopleths, a person who is inside the building will be protected by the structure, but one who is outside the building and unable to reach the shelter quick enough may receive fatal burns. Figure 5 shows the radiation received by target buffer zones around LPG tank.

To estimate thermal radiation damage to both people and structures at a distance, from the pool fire, the radiation at that distance is required. Table 4 shows estimated fire pool size and the thermal radiation. The thermal radiation buffer zone from pool fire hazard is also visually presented in Figure 6 .

CONCLUSIONS

This paper presented preliminary studies on the potential of BLEVE hazard. Theoretical investigations of various methods for calculating the physical effects of explosions and fires of vessels containing liquefied petroleum gases (LPG) in Faculty of Engineering, UPM, have been carried out with several physical models. Zones of high fatality and damage on construction have been classified on the location map. Mapping the visual display of information, has shown its capability as a useful tool in hazard analysis and risk management. GIS can be used to analyze and predict the BLEVE events with the aid of the mapping tools and models on the potential risk area.
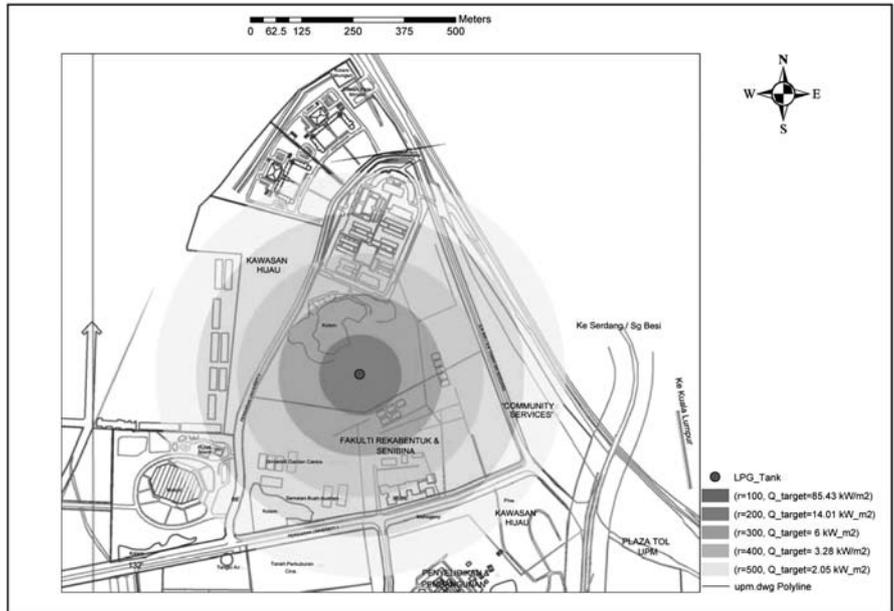

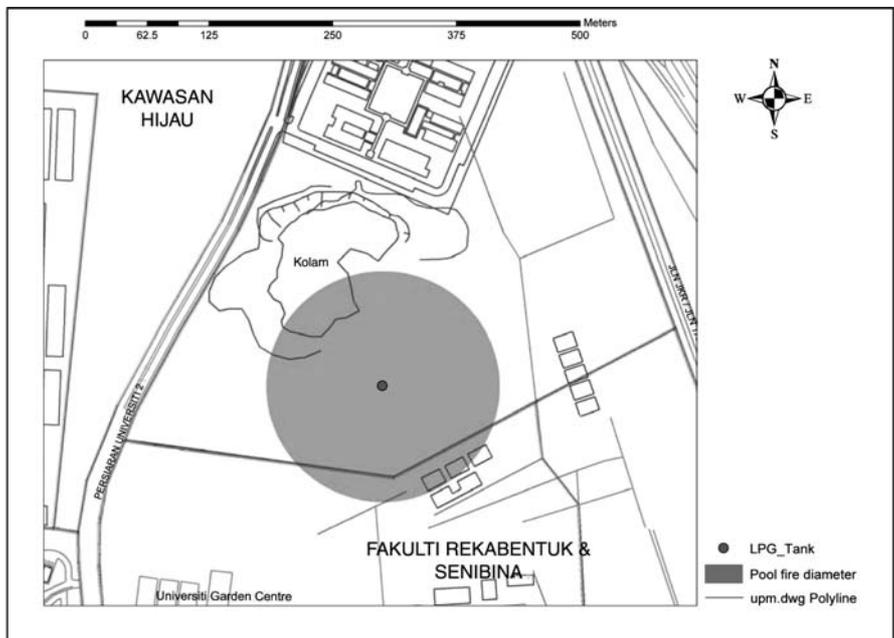*Figure 5: Radiation received buffer zones around LPG tank*

Figure 6: Thermal radiation from as function of pool fire diameter

Table 3: The radiation-received by a target

$r(m)$	$l\,(N/m^2)$	F_{21}	τ	$Q_{target}\,(kW/m^2)$
100	94.38	2.10	0.66	58.43
200	150.48	0.53	0.63	14.01
300	225.56	0.23	0.61	6.00
400	310.32	0.13	0.59	3.28
500	400.27	0.08	0.58	2.05

Table 4: Estimate the fire pool size and the thermal radiation

$M(kg)$	$A_p(m^2)$	$D(m)$	m	$L_f(m)$	$Q_R\,(kW/m^2)$
40,000	3642.99	68.12	0.099	85.92	$1.10*10^6$
60,000	5464.48	88.43	0.099	98.92	$1.65*10^6$
80,000	7285.97	96.34	0.099	109.32	$2.20*10^6$
100,000	9107.47	107.713	0.099	118.14	$2.75*10^6$
120,000	10928.96	117.99	0.099	125.86	$3.30*10^6$

Table A1: Eardrum Rupture Criteria for Exposure to Blast Overpressures

Likelihood of Eardrum Rupture	Peak Overpressure (kPa)
90%	84.12
50%	43.43
10%	22.06
1%	13.10

Table A2: Pressure effects on humans

Pressure (kPa)	Effect
35	Limit for eardrum rupture
70	Limit for lung damage
180	1% mortality
210	10% mortality
260	50% mortality
300	90% mortality
350	99% mortality

Table A3: Damage Estimates for Common Structures Based on Overpressure (These values are approximations)*

Pressure (kPa)	Damage
0.21	Occasional breaking of large glass windows already under strain
0.69	Breakage of small windows under strain
1.03	Typical pressure for glass breakage
2.07	"Safe distance" (probability 0.95 of no serious damage below this value); projectile limit; some damage to house ceilings; 10% windoe glass broken
2.76	Limited minor structural damage
3.4-6.9	Large and small windows usually shatter; occasional damage to window frames
4.8	Minor damage to house structures
6.9	Partial demolition of houses, made uninhabitable
6.9-13.8	Corrugated asbestos shatters; corrugated steel or aluminium panels, fastenings fail, followed by buckling; wood panels (standard housing), fastenings fail, panels blow in
13.8	Partial collapse of walls ans roofs of houses
13.8-20.7	Concrete or cinder block walls, not reinforced, shatter
17.2	50% destruction of brickwork of houses
20.7-27.6	Frameless, self-framing steel panel buildings demolished; rupture of oil storage tanks
27.6	Cladding of light industrial buildings ruptures
34.5	Wooden utility poles snap; tall hydraulic presses (40,000 Ib) in buildings slightly damage
34.5-48.2	Nearly complete destruction of houses
68.9	Probable total destruction of buildings; heavy machine tools (7000 Ib) moved and badly damaged, very heavy machine tools (12,000 Ib) survive

*V.J. Clancey, "Diagnostic Features of Explosion Damage," paper presented at the Sixth International Meeting of Forensic Sciences (Edinburgh, 1972)

Table A4: Effect of thermal radiation on construction [16]

Thermal radiation (kW/m2)	Effect	Distance (m)
37.5	Spontaneous ignition of wood after long exposure	124
23-25	Unprotected steel will reach thermal stress temperatures which can cause failures	151-157
	Non-piloted ignition of wood occurs	151
25	Cable insulation degrades	168-177
18-20	Piloted ignition of wood occurs	211
12.5	Thermal stress level high enough to cause structural failure. Minimum energy required for piloted ignition	
12.6	of wood, melting of plastic tubing	210
12	Plastic melts	215

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NOMENCLATURES

A_p	Pool area	m^2
D	Pool diameter	m
$D_{initial}$	Initial ground level hemisphere diameter	m
D_{max}	Peak fireball diameter	m
E	Surface emitted flux	kW/m^2
E_{TNT}	Energy of explosion of TNT	KJ/kg
F_{rad}	Radiation fraction, typically (0.25-0.4)	-
F_{21}	View factor	-
g	Acceleration of gravity	m/s^2
H_{BLEVE}	Centre height of fireball	m
H_w	Jet flame conical half-width at flame tip	m
k	Constant specific for each fuel	m^{-1}
l	Path length, distance from flame surface to target	m
L_f	Flame height	m
M	Initial mass of flammable liquid	kg
m	Mass burning rate per unit area	$Kg.m^2.s$
$m\infty$	Mass burning rate per unite area for an infinite pool	$Kg.m^2.s$
m_{TNT}	Equivalent mass of TNT	kg
P_w	Water partial pressure	N/m^2
P_0	Peak overpressure	kPa
Q_R	Heat radiation by fire	kW
$Q_{t \arg et}$	Radiation received by a black body target	kW/m^2
Q_T	Total rate of heat release	kW
r	Distance from the ground-zero point of the explosion	m
t_{BLEVE}	Fireball duration	s

Greek Symbols

η	Empirical explosion efficiency, 0.95	-
ΔH_c	Heat of combustion	KJ/kg
τ	Atmospheric transmissivity	-
κ	Fraction of total heat emitted as radiation	-
ζ	Efficiency of combustion, (it can be assumed 95%)	-
ρ_a	Ambient air density	Kg/m^3

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