ANALYSIS THE TOTAL BURN SURFACE AREA FROM BLEVE FIREBALL IMPACT AT DYNAMIC PARAMETER CONDITION

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***Abstract*—Feyzin disaster during 1966 in France will always leave a big mark in engineering industry as it involved many casualties. The disaster would make a perfect example of case study on impact of BLEVE fireball towards nearby occupants. The methodology to investigate BLEVE's characteristic, fireball's impact toward the effect of TBSA to human during Feyzin incident is by using BLEVE's dynamic model in the analysis. All scenarios involved during the analysis such as sphere tank design, chronology of accidents, and other relevants input is based on ARIA Feyzin incident report. The probability of occupants to get caught on fire and suffers different type of burns are determined with different distance from fireball. TBSA charts and age from JP Bull is simplified to RSM model, to determine the burn surface area on human's body.**

Keywords— Burn injury; BLEVE Fireball; LPG tanks; TBSA

I. INTRODUCTION

BLEVE is a short term for Boiling Liquid Expanding Vapour Explosion is one of a major hazard which have low possibility to happen but with high consequences. According to The Centre for Chemical Process Safety [1] has defined BLEVE as a sudden release of a large mass of pressurized superheated liquid to the atmosphere. Liquefied Petroleum Gas (LPG) tanks and Liquefied Natural Gas (LNG) tanks are the most popular equipment that were most certainly to BLEVE according to past accidents statistics. According to a research conducted by Tasneem [2], the leading root cause of BLEVE is from a fire (36%) with mechanical damage (22%) follow close.

On 4th January 1966, an operation were carried out to slowly drain the propane inside the spherical tank storage. Two of the valves were fully open on the bottom of the storage tank to speed up the operation. As the operation progressed, the valve on the top of the storage tank which was called as cracked valve, was closed and opened again repeatedly. However, much of a disappointment, there wasn't any flow came out of the valve. Most of the workers assumed that the valve was iced and turns out to be true when suddenly the gas gushed out violently. As the operator tried to control the situation by attempting to close the bottom valve but it turned out to be frozen too. The alarm rang loudly and attract the attention of pedestrians nearby as they curiously approached and stunned by it. According to the report, the vapor cloud dispersed through the streets, which it was a matter of times before disaster occurred. Unfortunately, a car was believed had sparked the vapor from its engine and fire ignited. [3]

It was said that approximately 90 minutes after initial leakage, the structure of the storage tank had failed completely and erupted, killing men nearby the incident. A wave of propane gas engulfed nearby buildings and other storage tank causing the skirt that supported the tank to collapse and emitted liquids from it. The casualties of this incident were immense as it was reported that, 18 people were killed and 81 others were injured. Five of the storage spheres were destroyed.

Most of the literature review found out that BLEVE did gave an impact based on radius distance from the centre of explosion. Each radius gave different impacts based on forces in unit MPa. Previous literature review had done some researches on BLEVE explosion on degree of burns. If the thermal heat radiation which came with immense forces can cause burns on human skins, then, the forces can also causes the human bones to breaks or fractures.

These questions lead us to several problem statements. First, the amount of BLEVE energy to cause a burn surface area damage on a body need to be investigate by using dynamic models in the analysis. Next, validation of probits with the actual casualties of BLEVE events from actual casualties. From these problem statements, an instant objectives need to be determined. First, the amount of BLEVE energy to cause a burn surface area damage on a body need to be determined. Next, the result of analysis needs to be validate and compare with the reported casualties of BLEVE events with the proposed probits.

In this study, impact of BLEVE explosion on the burn surface will be analysed according to a past BLEVE event that had sufficient amount of parameters. However, most of the research depends on probits done by various researchers was compiled by [4]. The probits were determined by overpressure released by BLEVE and thermal radiation emitted. Those probits might be the lead to a better research BLEVE fireball impacts on burn surface area of the body. Nonetheless, BLEVE is an important event that need to be researched to further understand the fireballs' characteristics.

II. METHODOLOGY

A. Procedure

These are the procedures that will follow throughout this research.

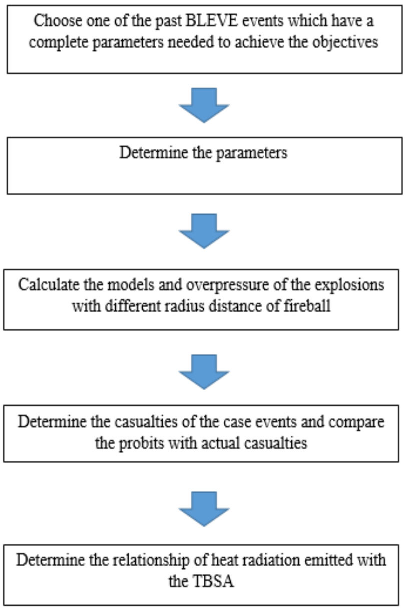

Figure 1: Methodology Procedure

This study are based on a simulation of Feyzin BLEVE disaster in France during 1966. It is a case study to compare the actual casualties with experimental casualties. During the accidents, there were 8 propane tanks and 4 butane tanks recorded that exploded but only one propane tanks were considered in order to determine the characteristic of fireball clearly [5]. Several parameters are recognized in order to fill up the methodology proposed.

Parameters	Feyzin
Filling Degree (%)	50%
Temperature (°C)	50
Volume tank (m3)	1200
Mass of explosions (kg)	23,274
Type of LNG	Propane
Pressure at explosion	4251200
Density of propane (kg/m3)	38.79
Heat of combustion	50329
Duration of fireball (s)	11.1163
Max diameter fireball (m)	194.4175
Max Height fireball (m)	255.1036
Partial pressure water	1149.256
nRad	0.4295434
Humidity relative (%)	0.5

Figure 2: LPG Feyzin Tank

These parameters are taken from previous various literature including Zoltan's literature [6] that happened during the moment of explosions. Filling degree will always be 90% in an assumption according to a [7] which are always feasible and properly designed to store any LNG. The mass of explosions are determined by the volume of the tank and the density of the propane. The density and propane's heat of combustion is based on thermodynamics properties. [8]

B. *Characteristic of fireball*

BLEVE fireball have two different sides moments of explosions which are growing phase and mature phase [9]. These phase each have its own equation to calculate diameter, height and duration of fireball. For maximum duration of fireball, this are its equation:

$$t_d = 0.9 \times M_{FB}^{1/4} \qquad (1)$$

Where,
t_d = Fireball duration (s)
M_{FB} = mass of released flammable material in the fireball (kg)

After that, the maximum fireball diameter are determined. However, during the trajectory of the diameter of fireball, fireball's diameter go through two phase which are growing phase and mature phase.

$$D(t)(m) = 8.664 \times M_{FB}^{1/4} \times t^{1/3} \qquad \text{For } 0 \le t \le \frac{1}{3} t_d \qquad (2)$$

$$D_{max} = 5.8 M_{FB}^{\frac{1}{3}} \qquad \text{For } \frac{1}{3} t_d \le t \le t_d \qquad (3)$$

The centre height of fireball can be time variant also according to (Zoltán Töröka, 2011). The equation were shown below.

$$H_{FB}(t)\ (m) = \frac{D(t)}{2} \qquad \text{For } 0 \le t \le \frac{1}{3} t_d \qquad (4)$$

$$H_{FB}(t)\ (m) = 3 \times \frac{D_{max}(t)}{2} \times t_d \qquad \text{For } \frac{1}{3} t_d \le t \le t_d \qquad (5)$$

For radiant heat fraction, there are certain energy released that emitted thermal radiation. The value of fraction usually ranges from 0.2 to 0.4 [10]. The radiant heat fraction can be deduced as follows:

$$\gamma_{rad} = 0.00325 . P^{0.32} \qquad (6)$$

Where,
P = pressure in the vessel just before the explosion, in Nm^{-2}

Emissive power can be calculated by using the radiant heat fraction. It also varies with time, reaching a maximum very quickly at the end of the fireball expansion and then decreasing slowly until extinction. It also have those two phases.

$$E_{max} = 0.0133 . \gamma_{rad} . \Delta H_c . M^{\frac{1}{12}} \qquad \text{For } 0 \le t_i \le t/3 \qquad (7)$$

$$E = E_{max}\left[\frac{3}{2}\left(1 - \frac{t_i}{t}\right)\right] \qquad \text{For } t/3 < t_i < t \qquad (8)$$

Next, the distance of maximum height of fireball and the targeted object are calculated to determine the thermal radiation dosage received.

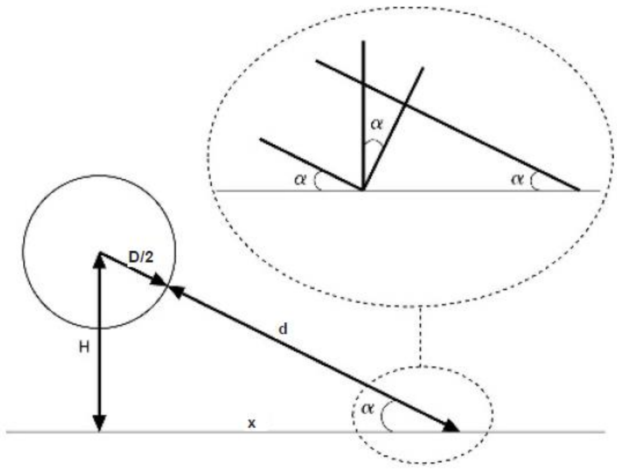

Figure 3: Trigonometry of fireball towards and distance of object

Then, the atmospheric transmissivity are accounts for absorption of thermal radiation by the atmosphere [9]. Each of them are differentiate by different water pressure and distance.

$$\tau = 1.53 . (P_W . d)^{-0.06} \qquad \text{For } P_W . d < 10^4 N . m^{-1} \qquad (9)$$

$$\tau = 2.02 . (P_W . d)^{-0.09} \qquad \text{For } 10^4 \le P_W . d \le 10^5 N . m^{-1} \qquad (10)$$

$$\tau = 2.85.(P_W.d)^{-0.12} \qquad \text{For } P_W.d > 10^5 N.m^{-1} \qquad (11)$$

Where,
P_W = partial pressure of water in the atmosphere (N m-2)
D = distance between the surface of the flame and the target

Water pressure can be calculated by determine the relative humidity of the water.

$$P_W = P_{wa}\frac{H_R}{100} \qquad (12)$$

Where,
P_{wa} = saturated water vapor pressure at the atmospheric temperature (N m-2)
H_R = the relative humidity of the atmosphere (%)

Water pressure can be obtained by different temperature:

$$\ln P_{wa} = 23.18986 - \frac{3816.42}{(T-46.13)} \qquad (13)$$

Next, view factor correspond to sphere and surface perpendicular to the sphere.

$$F_{max} = \frac{4\pi(D^2/4)}{4\pi\left[\frac{D}{2}+d\right]^2} = \frac{D^2}{4\left[\frac{D}{2}+d\right]^2} \qquad (14)$$

An average value of the emissive power can be calculated as the radiant heat emitted divided by the surface of the fireball:

$$E = \frac{\gamma_{rad}.M.\Delta H_c}{\pi.D^2.t} \qquad (15)$$

Where,
t = the time corresponding to the duration of the fireball (s)
M = the molecular weight of the fuel
ΔH_c = the heat of combustion (lower value) of the fuel (kJ kg-1).

Then, the radiation intensity that are perpendicular to the surface are determined because the radiation can travel in all directions.

$$I = E.F.E_P \qquad (16)$$
$$I_v = I.\cos\alpha \qquad (17)$$
$$I_h = I.\sin\alpha \qquad (18)$$

Finally, after calculating the radiation intensity, the dosage of thermal radiation received by targeted object are determined:

$$Dose = t.I^{4/3} \qquad (19)$$

The dosage that the targeted object received can cause burn damage towards the skins. Each type of burn damage are determined by the dosage. Moreover, probability of dying must also be calculated to determine the TBSA of an object.

$$Y = -39.83 + 3.02ln(t.I^{4/3}) \qquad \text{For 1}^{st}\text{ Degree Burn} \qquad (20)$$
$$Y = -43.14 + 3.02ln(t.I^{4/3}) \qquad \text{For 2}^{nd}\text{ Degree Burn} \qquad (21)$$
$$Y = -36.38 + 2.56ln(t.I^{4/3}) \qquad \text{For 3}^{rd}\text{ Degree Burn} \qquad (22)$$

Probability of dying are calculated:

$$\text{POD (Probability of Dying)} = [e^x/1] + e^x \qquad (23)$$

Where, $X = B_o + B_1 (age) + B_2 (\%TBS\ burn) + B_3 (age)^2$ (24)
B_0 = -5.22
B_1 = -0.1041
B_2 = 0.09843
B_3 = 0.002296

Full quadratic model equation,
$$y = -0.38320414 + 0.01671391x_1 + 0.00371284x_2 - 0.00006319x_1x_2 - 0.00002792x_1^2 + 0.00008139x_2^2 \qquad (25)$$

where,
y = mortality
x_1 = percentage of body area burned (second degree burn)
x_2 = age (find between 25-45)

III. Results & discussion

A. BLEVE Dynamic Model

During this research, BLEVE dynamic model is used to determine thermal dosage received by victims who were exposed in certain amount of time. Figure 4 shows thermal dosage received by human.

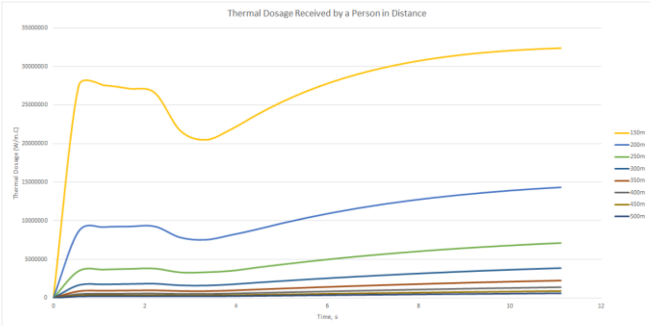

Figure 4: Thermal Dosage Received

Each object with different distance from center of fireball received different amount of thermal radiation received from each other as shown in figure. The thermal radiation increase radically at first 0.8 seconds for all distance but it was stagnant for several seconds but it increase slightly until the thermal dosage start to be consistent during the mature phase. However, the characteristics of fireballs obtained didn't match the previous literature proposed by Zulkifli [11] . The results obtained by him was that the thermal radiation during growing phase kept on growing until 3 seconds and decline during mature phase. Maximum thermal radiation of fireball only peaked at a split seconds during early on explosions.

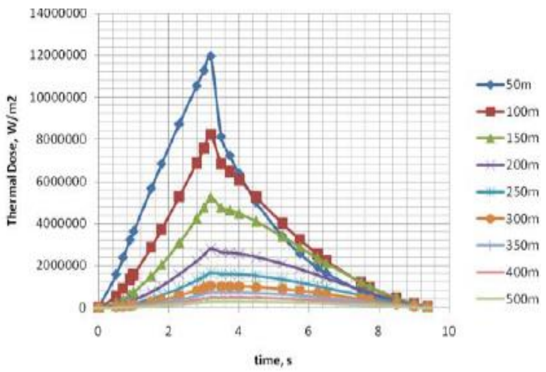

Figure 5: The Amount of Thermal Dose Received in Relation to the Distance

The reasons for the difference are not because of the methodology used but it was caused by the quantity input mass of propane from Feyzin incidents. In Zulkifli's research [11], the quantity of remaining mass that are still left inside the sphere tank, TK 61443, that were used to calculate impact of BLEVE incidents, which means, the total mass propane that were stored inside during Feyzin ARIA report, were taken off from the quantity mass of propane that were released from the sphere tank's valve that was failed to closed by the operator for several minutes followed by the flashfire and the mass of jetfire that were released by the relief valve of the sphere tank. Meanwhile, during this analysis, the parameter of 50% filling degrees, 50°C temperatures and 1200 m^3 sphere tank were considered. Generally, both maximum thermal dosage decrease as the further the distance of object from the center of fireball because of the loss potential of energy in the atmosphere during the explosion over time. The models couldn't prove growth and mature phase of fireball as the dosage of fireball only peaked at the start of fireball for a split second only. The reason for the statements is because during this phase, the energy stored were released rapidly until the energy dissipated the total mass fuel of fireball involved.

Atmospheric transmissivity contributes a lot towards the BLEVE dynamic model. It determines the potential loss of energy when it travels through the atmospheres. The atmospheric transmissivity accounts for the absorption of the thermal radiation by the atmosphere, essentially by carbon dioxide and water vapor. It can be concluded that during the growing phase the thermal dosage are unstable and it will slowly stabilize during mature phase.

B. Relationship between Thermal Radiation and Burn Degree

Thermal radiation received by human during BLEVE can cause serious burn injury. Those three type of burns are differentiate by level of damage inflicted on human body. The level of injury can be determine by thermal radiation and TBSA percentage inflicted. each of the probits were used as an equation to determine the possibility of type of injury that a person inflicted in each distance varies with time from the Feyzin accidents.

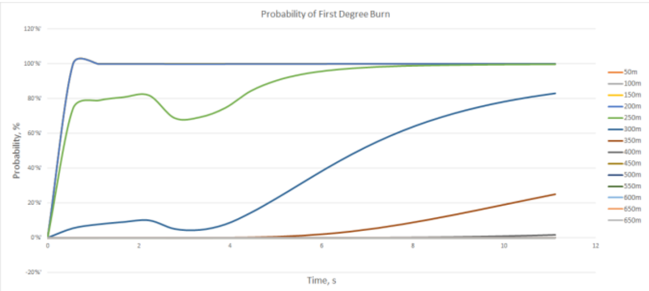

Figure 6: Probability of First Degree burn

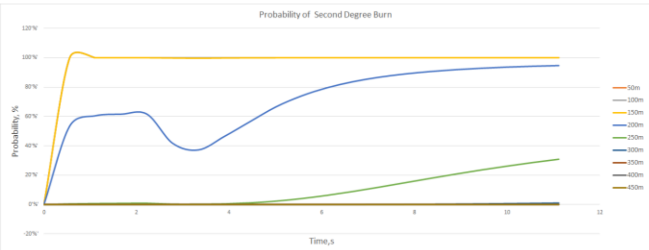

Figure 7: Probability of Second Degree burn

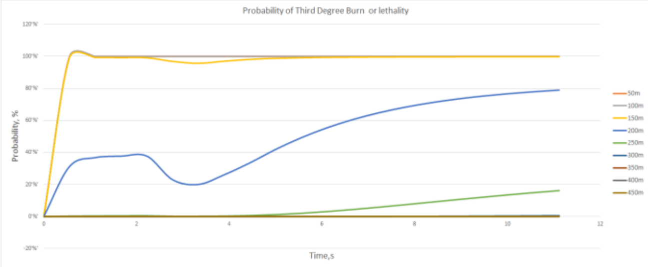

Figure 8: Probability of Third Degree burn

It is found that the highest probability of a person to be inflicted with third degree burn are at a distance at least 200 meters from the center of fireball during full fireball duration. Then, a person might inflicted a first degree burn as far as 400 meters from center of fireball. However, during the peak of thermal radiation, a person as far as 300 meters will cause a third degree burns which means instant deaths. No people can escape the radiation because it only takes 0.8 seconds for the radiation to reach its peak. Each graph has the same trends which that the radiation will peak at around 0.8 seconds and decline for a while during growth phase and increase back during mature phase. The victims can probably feel the thermal radiation for about 12 seconds or maybe more. The person standing in a radius of 250 meters from center of fireball will likely to suffer from a third degree burn for a full 12 seconds during the thermal radiation and may not survive. The biggest uncertainty is whether the victims will suffer from a third degree burn or not. A further research are needed on order to answer the uncertainty of the analysis.

However, the results of probits didn't match with the previous literature results. According to Zulkifli [11], the probits start to increase its probability around at 1 second during growth phase which are different from the results obtained. It is maybe because of slightly different equation models and the amount of mass of fireball differences.

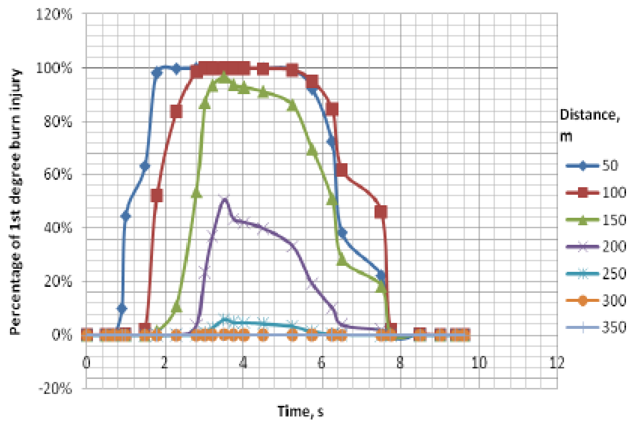

Figure 9: Probability of 1st degree burn injury in relation with time at a distance of 50 m, 100 m, 150 m, 200 m, 250 m, 300 m, and 350 m.

However, the probability of degree burn injury did decrease over distance periodically. Both first degree burn injury probability did decrease over distance from 50 to 350 meters.

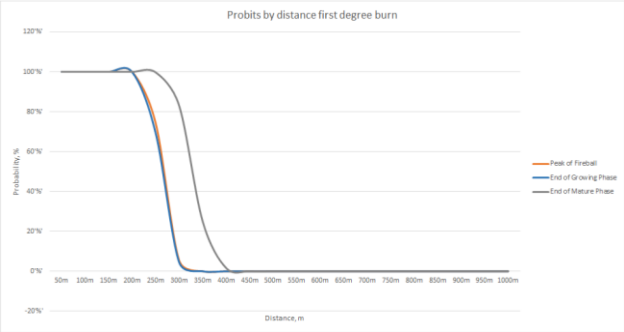

Figure 10: Probability of First Degree Burn at Certain Phase

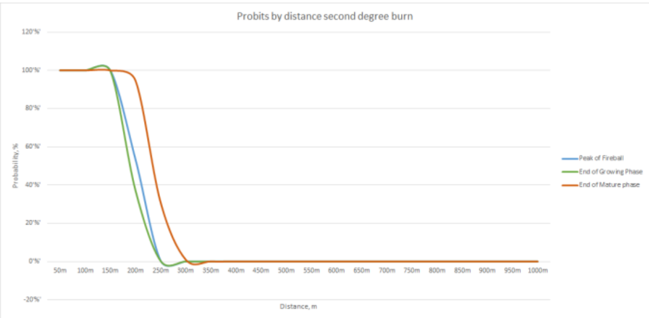

Figure 11: Probability of Second Degree Burn at Certain Phase

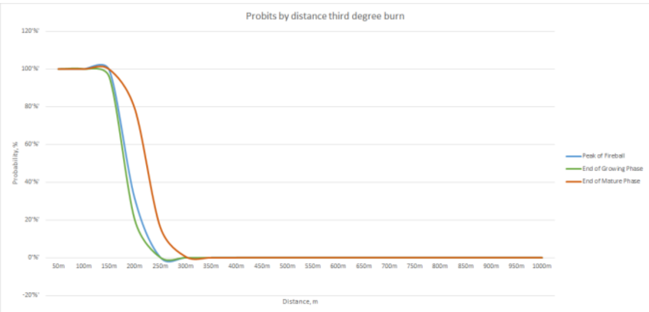

Figure 12: Probability of Third Degree Burn at Certain Phase

Each probits will decrease gradually in same pattern as the probability of probits will decrease in small period of time. The probability of people got a first degree burn are at maximum of 650 meters while the maximum distance of people caught a second degree burn are at 500 meters. Lastly, there isn't much difference between the probability of people caught a third degree burn and the second one. Figure 10, 11, 12 can be compared to Zoltan's research [6] to compare the percentage of burn probability in dynamic model.

C. Effect of Thermal Radiation towards TBSA and Probability of Dying

Every disaster that involve thermal radiation expansion will result in various degrees of burn injuries. However, to determine the degrees of injuries, a models of calculation are needed in order to obtain the degrees of consequences. There are a traditional method to determine the degrees of a burn injuries which is determined by observation of the victims' injuries in hospital. However, with limited access and records, the method seems impossible to execute so a quantitative analysis is the most plausible method to determine the TBSA of a victim's injury.

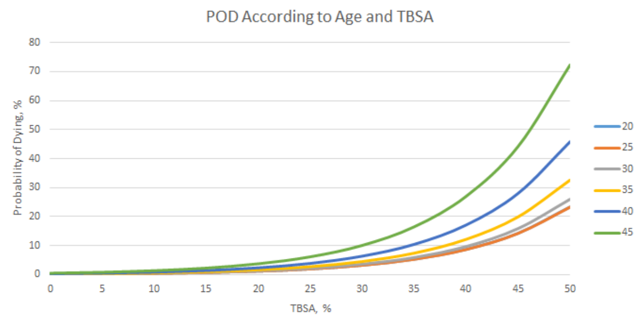

Figure 13: POD According to Age and TBSA in 2nd degree burn

In figure 13, the trend of the graph is that every age group will increase exponentially with the TBSA and POD. The graph increase in probability of dying as the age group increase. The reasons for limited age group is that during the day, the possible age of group of workers and passerby are around 20 to 45 age of groups. For a second degree burn, if a victim with a high probability of second degree burn during the disaster were impacted with more than 15% TBSA are consider a serious injury [12]. In figure 13, 15% TBSA have a POD of below than 10% which means there are a higher probability of casualties during the Feyzin's explosion. According to a research conducted by Zulkifli [11] on Bull Chart called "Mortality Probability Chart" [13], which an analysis to determine the relationship between Thermal Radiation Dose and Probability of Dying.

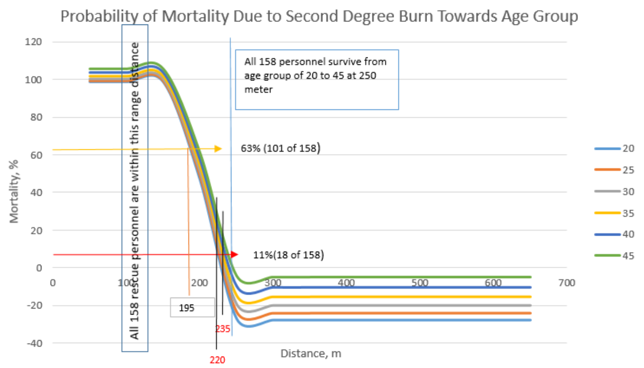

Figure 14: Mortality of Victims towards Distance by Age Group during Peak Thermal Dosage

In figure 14, the graphs shows the mortality rate of victims towards distance by age group during peak thermal dosage. The probability for victims inflicted with second degree burn in figure 7 and group age from 20 to 45 will be used in equation 25 to calculate the mortality of second degree burn victims. The victims as far as 150 meters will have a mortality of 100% which means they will not survive at all. However, the victims' mortality percentage slowly decrease for the next 200 meters until 300 meters. The victims will survive after 300 meters. It would take a total of 32,000,000 kW/m^2 of thermal dosage that will result in 100% probability of a victims will not survive the burns. A plausible explanation with the amount of casualties inflicted with 18 deaths and 83 injuries during the explosion because the distance between nearby bystanders and the LPG tank is 22 meters [6]. However, a more consistent model are needed in order to get a more consistent result and analysis towards a case study.

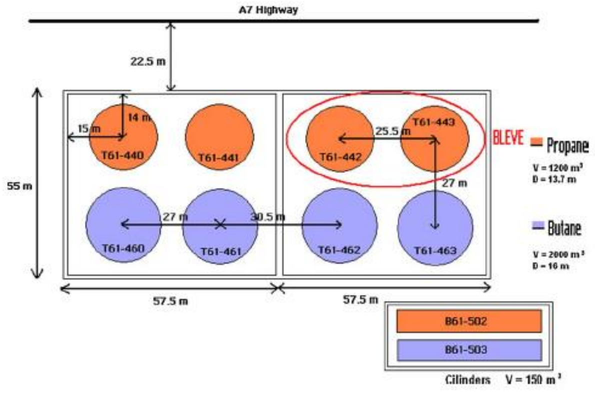

Figure 15: Feyzin's plan during the BLEVE

IV. CONCLUSION

This study has proven the objective have been accomplished. The thermal radiation does have an effect on victims nearby the center of fireball by damaging the skin for during the fireball. The model defining the dynamic characteristic of fireball has a bit of flaw as it does not resemble past literature because during growing phase, the thermal dosage should increase whereby during this study the dosage are stagnant but it decrease linearly during mature phase. It is proven that the atmospheric transmissivity does decrease the dosage along time and distance. However, thermal dosage in this study might be plausible since the model for dynamic BLEVE provided by J. Casal [10] are consistent until probits. During probits model, the analysis also did not represent the previous literature because of the difference in phases. However, the impact of burn injury towards different distance of fireball is plausible and because the mass of fireball are high. After that, the TBSA and age does effect on probability of dying for second degree burn. As the age increase on 30% TBSA, the probability of dying also increase with an age group of 45 have a maximum of 11% chance of dying. It takes a total of 32,000,000 kW/m^2 of thermal dosage to make a victim mortality to increase up to 100%. As for the second objective, the casualties of the real life-time event compare to the analysis in case study are realistic since the probits of second and third degree burn at 100% is at 150 meters for a whole duration of fireball. However, more consistent model were needed to estimate the number of casualties in more realistic figure.

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