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Quantitative Consequence Analysis and Emergency Planning for Propane Storage Incidents: A Framework for Major Hazard Installations

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ABSTRACT

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This study presents a detailed quantitative consequence analysis for a major hazard installation storing 30 tonnes of propane. Thermal radiation and overpressure effects from potential catastrophic scenarios including a Boiling Liquid Expanding Vapour Explosion (BLEVE), a sustained jet fire, and a vapour cloud explosion (VCE) were modeled to establish fatality probability distances. Using probit functions and recognized industry models, the analysis determined the distances corresponding to 5%, 50%, and 95% fatality rates for each scenario. A population exposure assessment, incorporating day/night demographics and sheltering assumptions, estimated potential fatalities. For the BLEVE scenario, predicted fatalities were 158 during daytime and 32 at night, significantly higher than for jet fire or VCE scenarios. The study underscores the severe hazard posed by BLEVEs and highlights the critical role of robust, rehearsed on-site and off-site emergency plans in mitigating consequences. The methodology demonstrates the application of quantitative risk assessment (QRA) to inform safety distances and emergency response planning, while also acknowledging inherent uncertainties in such predictive models.

تحليل العواقب الكمية والتخطيط للطوارئ لحوادث تخزين البروبان: إطار عمل للمنشآت ذات المخاطر الكبرى.

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المُخلص

تقدم هذه الدراسة تحليلاً كمياً شاملاً لعواقب كارثة محتملة في منشأة تخزين غاز البروبان، حيث يتم تخزين 30 طناً من البروبان .تم نمذجة تأثيرات الإشعاع الحراري والضغط الزائد الناتجة عن سيناريوهات كارثية محتملة تشمل انفجار بخار سائل متمدد مغلي وحريق نفاث مستمر وانفجار سحابة بخارية بهدف تحديد المسافات المحتملة للوفيات .باستخدام دوال بروبيت ونماذج التنبؤية معروفة حدد التحليل المسافات المرتبطة بمعدلات وفيات بنسبة 5 %و50 %و95 %لكل سيناريو .قدّر تقييم تعرض السكان الذي شمل التركيبة السكانية ليلاً ونهاراً وخصائص المأوى عدد الوفيات المحتملة .بالنسبة لسيناريو انفجار البخار السائل المتمدد المغلي بلغ عدد الوفيات المتوقعة 158 حالة وفاة خلال النهار و32 حالة وفاة ليلاً وهو عدد يتجاوز بكثير حالات الحريق النفاث أو انفجار سحابة البخار. تؤكد الدراسة على الخطر الجسيم الذي تمثله انفجارات البخار السائل المتمدد المغلي وتبرز أهمية وجود خطط طوارئ فعالة ومُدربة بشكل جيد سواء داخل الموقع أو خارجه في التخفيف من عواقبها .توضح المنهجية تطبيق التقييم الكمي للمخاطر لتحديد مسافات الأمان والتخطيط للاستجابة للطوارئ بأستخدام نماذج تنبؤية متطورة

الكلمات المفتاحية: *انفجار الغازات المتمددة والمغلّفة؛ انفجار سحابة البخار؛ حريق نفاث؛ التخطيط للطوارئ؛ تحليل بروبيت؛ المخاطر الكبرى و سلامة العمليات*

1 Introduction

The safe operation of major hazard installations handling large inventories of flammable materials, such as liquefied petroleum gas (LPG), remains a major challenge for the global process industries (Bariha et al., 2023). These facilities, integral to energy supply chains and chemical manufacturing, are defined by the presence of substantial amounts of substances subjected to high pressure, presenting a continuous potential for catastrophic loss of containment (Shawail, Zaid, Osman, et al., 2025). The release and ignition of these substances can result in vital fire and explosion events, such as Boiling Liquid Expanding Vapour Explosions (BLEVEs), jet fires, and vapour cloud explosions (VCEs) (Stawczyk, J., 2003).. The impact of these events extend beyond the confines of plant boundaries, presenting significant risks to onsite personnel, nearby communities, essential infrastructure, and the environment (Shawail, Zaid, & Buaisha, 2025). This is evidenced by historical disasters at locations such as Feyzin, France (1966) (Török, Z et al., 2011), San Juan Ixhuatepec, Mexico City (1984) (Pietersen, C. M, 1988), and more recently, the 2020 explosion at the Beirut port involving ammonium nitrate (Al-Hajj et al., 2021; BBC, 2020). In an era of increasing public awareness, regulatory scrutiny, and industrial urbanization, the development of robust, science-based frameworks for hazard analysis and emergency response is not merely an operational necessity but a core social and ethical responsibility for engineers and safety professionals.

Quantitative Consequence Analysis (QCA) has evolved as the fundamental engineering methodology for translating the physical properties of hazardous materials into an understanding of potential incident outcomes. At its core, QCA employs a suite of empirical and phenomenological models to predict the intensity of physical phenomena, including thermal radiation, blast overpressure, and toxic concentration as a function of distance from a postulated release (Mannan, 2012). These predictions are often coupled with probit functions, which statistically correlate the intensity and duration of a harmful effect with a probability of specific outcomes, such as fatality or injury. The primary utility of QCA lies in its ability to generate objective, defendable answers to critical safety questions: How far could the effects of an explosion reach? What areas should be evacuated in an emergency? Where should land-use restrictions be applied?. QCA directly influences the design of safety systems, the determination of safety distances for land-use planning, and the tactical parameters of both on-site and off-site emergency plans (CCPS, 1999). Additional advancements have focused on enhancing the accuracy of these models through computational fluid dynamics (CFD) simulations. These simulations are more adept at addressing complex geometries, atmospheric conditions, and the impacts of congestion on vapor dispersion and explosion dynamics (Middha, 2010; Skjold, T., 2018).

Among the suite of potential incidents, the BLEVE represents one of the most severe and complex hazards associated with pressurized flammable liquid storage. A (BLEVE) occurs when a vessel containing a superheated liquid experiences catastrophic failure, leading to rapid vaporization, intense combustion, a significant fireball, and frequently the projection of destructive debris (Birk, 1996). The 1998 fire at a LPG depot in Ulsan, South Korea, which involved multiple BLEVEs and highlighted chain-reaction risks, serves as a stark reminder of its destructive potential (Park, 2006). Current studies have focused on more accurate modeling of the dynamics of BLEVE fireballs, particularly examining how different modes of tank failure, such as rocketing and fragmentation, affect the lift-off and geometry of fireballs (Landucci et al., 2017). Complementary hazards, such as prolonged jet fires resulting from pipework failures, pose a continuous thermal risk that has the potential to trigger cascading effects by affecting surrounding equipment. The analysis of two-phase flashing jet releases, crucial for accurate source term estimation in propane and other liquefied gas releases has been refined in recent studies, improving the prediction of mass flow rates and flame characteristics (Cormier et al., 2009). The modeling of vapor cloud explosions (VCEs) has evolved considerably from basic TNT-equivalent methods to more advanced techniques, such as the Multi-Energy Method and computational fluid dynamics (CFD)-based simulations. These modern approaches more effectively account for the effects of congestion and confinement on the intensity of explosions (van den Berg, 1985). These evolving models form the essential technical toolkit for any modern QCA.

However, a precise quantitative understanding of hazards is rendered incomplete without an equally robust and actionable plan for emergency response. Emergency planning is the critical bridge between hazard identification and the mitigation of real-world consequences. It transforms the static outputs of a risk assessment zones, distances, and probabilities into dynamic, coordinated procedures for human action (Lees, F. P., 2012). A robust emergency plan is a complex, integrated system encompassing immediate incident control, personnel accountability, communication protocols, medical response, public alerting, and inter-agency coordination (HSE, 2015). The synergetic relationship between QCA and emergency planning is unequivocal: the former defines the "what" and "where" of the potential disaster, while the latter defines the "who," "how," and "when" of the response. This integration is a cornerstone of modern process safety management frameworks, such as the risk-based approach advocated in regulations like the EU's Seveso III Directive, which explicitly requires external emergency plans based on hazard assessments (EU, 2012).

Traditional QCA often relies on conservative, generic assumptions regarding meteorological conditions, ignition probabilities, and human behavior, which can lead to over or under estimation of risks (Taveau, 2010). Furthermore, the human and organizational elements of emergency response often the weakest link are difficult to quantify. Studies on major accidents consistently cite failures in emergency preparedness, including inadequate procedures, poor communication, and lack of effective training and drills, as contributing factors to the escalation of consequences (Kletz & Amyotte, 2010). In addition, academic research has highlighted the necessity for a more integrated and holistic approach. This includes the implementation of dynamic risk assessment models that adjust probabilities in accordance with real-time conditions, as well as the utilization of serious gaming and virtual reality for emergency training aimed at enhancing decision-making under stress (Zaalberg & Midden, 2013), and greater emphasis on community engagement and public warning systems to reduce public vulnerability (Sorensen, 2000).

This article investigates the integrated need by presenting a comprehensive case study of a theoretical 30-tonne propane storage facility. The study covers two interrelated objectives; firstly, it conducts a comprehensive comparative quantitative risk assessment (QCA) for three primary incident scenarios: a boiling liquid expanding vapor explosion (BLEVE), a jet fire resulting from a ruptured pipeline, and a vapor cloud explosion (VCE) that occurs due to vapor release. It utilizes established probit methodologies in conjunction with source term models to compute fatality probability distances, consequently generating a distinct, quantitative ranking of hazard severity. Secondly, it is crucial to integrate these technical findings into a coherent and applicable framework for both on-site and off-site emergency planning. By explicitly correlating the calculated hazard zones (e.g., 5%, 50%, and 95% fatality contours) with specific emergency action such as evacuation radii, shelter-in-place directives, and responder approach routes. This work demonstrates how engineering analysis must directly and tangibly inform operational preparedness. In doing so, it argues that true process safety resilience is achieved only when rigorous technical hazard assessment and meticulously rehearsed emergency management are developed not in isolation, but as two inseparable components of a unified risk reduction strategy.

2 Materials and Methods

2.1. Scenario Definition and Source Term Modeling

The research assumed a propane storage vessel containing 30,000 kg (30 tonnes) of product at a storage pressure of 1.72 MPa (250 psig). Three failure scenarios were analyzed:

- Scenario 1 (BLEVE): Catastrophic failure of the tank following external fire impingement, leading to a fireball.
- Scenario 2 (Jet Fire): Full-bore rupture of a 50 mm diameter pipe, resulting in a sustained directional flame.
- Scenario 3 (VCE): Full-bore rupture of a 50 mm diameter pipe, resulting in the development and subsequent ignition of a flammable vapor cloud within a congested plant area (10m x 15m x 8m).

2.2. Consequence and Fatality Distance Modeling

For thermal hazards (BLEVE and Jet Fire), the fatality analysis was based on radiation dose.

- Fireball Characteristics:

The BLEVE fireball diameter (D) and duration (t) were calculated using empirical correlations from

(Lees,1996):

$$D = 5.8 * M^{(1/3)}$$

$$t = 0.45 * M^{(1/3)} \text{ (for } M < 37{,}000 \text{ kg)},$$

where M is the fuel mass (kg).

- Thermal Radiation Intensity:

The received thermal radiation intensity (I) at a distance was calculated using solid flame models, incorporating view factor (F), surface emissive power (E), and atmospheric transmissivity (τ): $I = F * E * \tau$. View factor geometry and atmospheric attenuation ($\tau = 1 - 0.056 \ln(x)$) were applied.

View factor of fireball for a vertical surface is given as (LEES, 1996):

$$F = \frac{X(\frac{D}{2})^2}{(X^2 + H^2)^{3/2}}$$

Where x is the distance measured from a point on the ground beneath the center of the fireball (Figure 1). H is the distance from the center of the fireball to the ground $H \geq 0.5D$ Which is taken as 0.5D.

For the solid flame model, emissive power can be the surface estimated as (LEES, 1996):

$$E = 235P^{0.39}$$

Where P is the pressure of the fuel before vessel failure in MPa. This can be used for pressures ≤ (2 MPa). Propane is normally stored at a pressure of 250 psig (1.7236875 MPa)

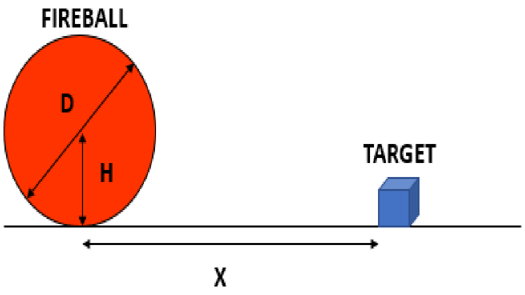

Fig. 1: Scheme of the geometry of a ground level fireball.

- Jet Fire Release Rate: A two-phase release model was employed to determine the mass flow rate for the jet fire scenario, based on the thermodynamic properties of propane (Zhou, K., et al., 2016; Quezada, L. A., et al., 2020).

$$q = \frac{f\, H_C\; m\; \tau}{4\pi\, X^2}$$

Where, q: intensity received by target (kW/m^2), f: fraction of heat radiated, Hc : Heat of combustion (kJ/kg), m : mass burning rate (kg/s), X: distance to the target (m), τ: transmittivity $= (1 - 0.056 \ln X)$

Assume that the mass burning rate (m) is equal to the mass release rate (w) kg/s. Assume that the propane is released as saturated two-phase flow. The release rate of the saturated two-phase flow is given as (Leung, J.C.,1986; Fauske et al., 1988):

$$W = \frac{C_D\, A\, h_{fg}}{V_{fg}\,(C_{PL}\, T)^{0.5}}$$

Where, W: release rate, C_D: discharge coefficient, A: cross sectional area (m^2), hfg: Heat of vaporisation (J/kg), V_{fg} : Difference between vapour and liquid specific volumes (m3/kg), C_{pL}: Liquid specific heat (J/kgK), T: Storage temperature (K)

- Fatality Probability: Thermal fatality probability was determined using the standard probit equation (Lees, 1996; CCPS,1999):

$$Yt = -14.9 + 2.56 \ln(I^{(4/3)} * t).$$

Where, I is the heat intensity and t is the duration of the fireball.

Distances for 5% (Y=3.36), 50% (Y=5.00), and 95% (Y=6.64) fatality were solved iteratively.

- For the VCE scenario, the Multi-Energy Method was employed.

Overpressure Calculation: Fatality from blast overpressure was linked using the probit (Lees, 1996; CCPS, 1999): $Yp = -77.1 + 6.91 \ln(P)$,

where P is the peak overpressure(N/m²).

Hence; P= e^([(Y+77.1)/6.91])

- Scaled Distance: The scaled distance (Rs) associated with the required overpressure was obtained from standard Multi-Energy charts (van den Berg, A. C.,1985). This was converted to a physical distance (X) using:

$$X = Rs * (E / P_0)^{(1/3)} ,$$

$$\text{thus; } R_S = \left[\frac{X}{E^{\frac{1}{3}}}\right] P_0^{\,1/3}$$

where E is the combustion energy of the confined vapour cloud (assumed stoichiometric at 3.5 MJ/m³) and P_0 is atmospheric pressure.

2.3. Population Exposure and Fatality Estimation

The calculated hazard distances were translated into potential fatalities through a systematic exposure assessment (Lees, 2012; CCPS, 2010). This process involved three steps: zone definition, population estimation, and fatality calculation, with distinct assumptions for day and night scenarios.

2.3.1. Zone Area Calculation:

The hazard footprint for each scenario was divided into three concentric annular zones based on the calculated distances corresponding to 5%, 50%, and 95% fatality probabilities ($R_{5\%}$, $R_{50\%}$, $R_{95\%}$). The area of each zone (A_{zone}) was calculated using standard circular geometry principles for hazard zone delineation (Mannan, 2012):

$$A_{95\%} = \pi R^2_{95\%}$$

$$A_{50\%} = \pi R^2_{50\%} - A_{95\%}$$

$$A_{5\%} = \pi R^2_{5\%} - (A_{95\%} + A_{50\%})$$

These equations derive from the fundamental principle that the area of an annular region equals the difference between the areas of larger and smaller circles (CCPS, 1999).

2.3.2. Exposed Population Estimation:

The number of people exposed within each zone (Nexposed,zone) was estimated using assumed population densities and outdoor fractions, following established practices for population-at-risk estimation (Stamber et al., 2016):

$$N_{exposed,zone}=(A_{zone}\times D\times F_{public}) + (W_{total}\times F_{worker})$$

Where:

- D = Population density (10,000 persons/km² for day; 1,000 persons/km² for night) (Lees, 2012)
- F_{public} = Fraction of public outdoors (assumed 0.10) (HSE, 2015)
- W_{total} = Total on-site workers (15 for day; 2 for night)
- F_{worker} = Fraction of workers outdoors (assumed 0.15) (CCPS, 2010)

. Fatality Calculation:

The final fatality estimates for each zone depended on the scenario (Mannan, 2012):

For BLEVE**:** A single effective fatality probability ($P_{eff} = 0.75$) was applied to all exposed individuals, based on an assumed 25% survival chance for outdoors personnel accounting for behavioral responses (Hymes, 1983):

$$Fatalities_{BLEVE,zone} = N_{exposed,zone} \times 0.75$$

For Jet Fire & VCE: The zone-specific fatality probability (P_{zone}) was applied, using the probit-derived probabilities that defined the original hazard distances (CCPS, 1999):

$$Fatalities_{JF/VCE,zone} = N_{exposed,zone} \times P_{zone}$$

Where P_{zone} takes values of 0.95, 0.50, or 0.05 corresponding to the 95%, 50%, and 5% fatality zones respectively

3 Results and Analysis

3.1. Calculated Hazard Distances

The findings of the consequence modeling are summarized in Table 1, based on the data provided and the equations outlined in Section 2.2.

Table 1: Summary of Calculated Fatality Distances for Propane Incident Scenarios

Scenario	**Fatality Probability**	**Thermal Intensity / Overpressure**	**Hazard Distance (m)**
BLEVE (Fireball)	**5%**	**29.1 kW/m²**	**210**
	50%	**47.1 kW/m²**	**152**
	95%	**75.9 kW/m²**	**92**
Jet Fire	**5%**	**40.4 kW/m²**	**24.75**
	50%	**65.3 kW/m²**	**19.55**
	95%	**105.6 kW/m²**	**15.5**
VCE	**5%**	**1.13 bar**	**22.48**
	50%	**1.43 bar**	**19.90**
	95%	**1.80 bar**	**16.60**

The (BLEVE) exhibits the largest hazard footprint, with a 95% fatality zone extending to 92 meters, in contrast to 15.5 meters for a jet fire and 16.6 meters for a (VCE).

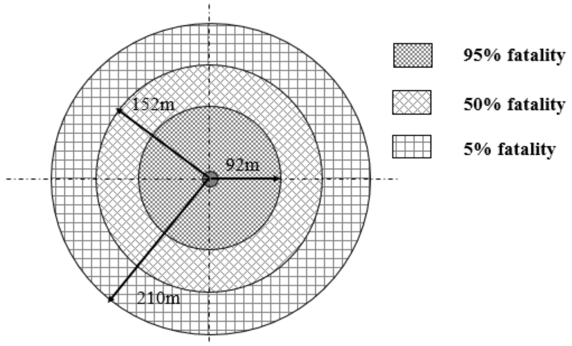

Fig. 2: Shows Fatality Distances for BLEVE

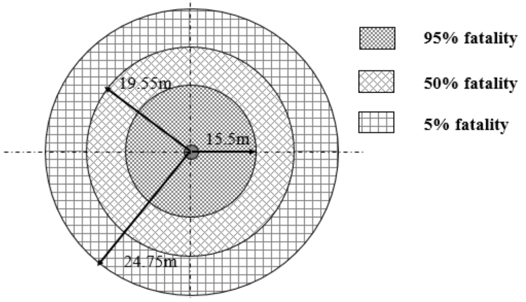

Fig. 3: Illustrations Fatality Distances for Jet fire

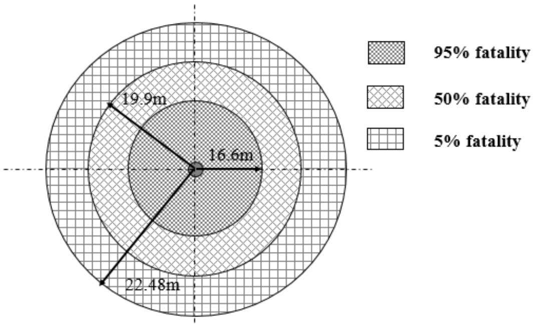

Fig.4: Presents Fatality Distances for VCE

3.2. Estimated Fatalities and Implications

The population exposure assessment yielded the potential fatalities shown in Table 2. The BLEVE scenario accounts for over 95% of the total estimated risk from the incidents studied, with daytime fatalities an order of magnitude higher than at night due to assumed population density.

a) To evaluate the number of fatalities resulting from BLEVE.

Using the data provided and the equations specified in Section 2.3, the number of fatalities resulting from BLEVE during daytime and nighttime has been determined in the summary below in tables 2 and 3.

Table 2: The number of fatalities resulting from a BLEVE during daytime.

	Area (m^2)	**Number of people in the area (N) *1.5**	**Number of people in public outdoor (N1) = 0.1*N**	**Number of workers outdoor (N2) = 0.15*15**	**Number of people outdoor exposed to thermal radiation that cause fatality Nt = 0.75* (N1 + N2)**	**Number of fatality**
A95%	**26590.44**	**399**	**40**	**2**	**31**	**31**
A50%	**45992.9**	**690**	**69**	**1**	**53**	**53**
A5%	**65960.896**	**990**	**99**	**0**	**74**	**74**
Total number of fatality						**158**

Table 3: The number of fatalities resulting from a BLEVE during nighttime**.**

	Area (m^2)	Number of people in the area (N)*3	Number of people outdoor (N1) = 0.1*N	Number of worker outdoor (N2) = 0.15*2	Number of people exposed to thermal radiation Nt = 0.75* (N1 + N2)	Number of fatality
A95%	**26590.44**	**81**	**8**	**0**	**6**	**6**
A50%	**45992.9**	**138**	**14**	**0**	**11**	**11**
A5%	**65960.896**	**198**	**20**	**0**	**15**	**15**
Total number of fatality						**32**

b) To estimate the number of fatality as a result of jet fire.

Using the equations from Section 2.3, number of fatalities due to jet fire were calculated during daytime and nighttime (Tables 4 and 5):

Table 4: The number of workers at (day/ night) time.

Distance (m^2)	Daytime People/100m^2	Night time People/100m^2	People at day	People at night
481.1	**1**	**0.1**	**4.811**	**0.4811**
300.18	**1**	**0.1**	**3.0018**	**0.30018**
188.69	**1**	**0.1**	**1.8869**	**0.18869**
Total			**9.6997**	**0.96997**

Table 5: The number of fatalities resulting from a jet fire during (day / night) time.

% Fatalities	Distance	Fatalities at daytime	Fatalities at night time
5%	**481.1**	**0.24055**	**0.02405**
50%	**300.18**	**1.5009**	**0.15009**
95%	**188.69**	**1.79255**	**0.1792555**
Total		**4**	**0.3534**

c) To determine the number of fatalities resulting from VCE

Tables 6 and 7 display the number of fatalities resulting from vapor cloud explosions (VCE), calculated using the equations detailed in Section 2.3.

Table 6: The number of workers at (day/ night) time.

Distance (m^2)	**Daytime People/100m²**	**Night time People/100m²**	**People at day**	**People at night**
396.9	**1**	**0.1**	**4**	**0.3969**
311	**1**	**0.1**	**3**	**0.311**
216.4	**1**	**0.1**	**2**	**0.2164**
Total			**9**	**0.9243**

Table 7: The number of fatalities resulting from a VCE during (day/night) time.

% Fatalities	**Distance**	**Fatalities at daytime**	**Fatalities at night time**
5%	**396.9**	**0.19845**	**0.019845**
50%	**311**	**1.555**	**0.1555**
95%	**216.4**	**2.0558**	**0.20558**
Total		**4**	**0.38**

Summary of Findings

Scenario	**Estimated Fatalities (Day)**	**Estimated Fatalities (Night)**
BLEVE	**158**	**32**
Jet Fire	**4**	**0.35**
VCE	**4**	**0.38**
Total	**166**	**~33**

4 Discussion

4.1. Evaluation of Results Associated with Hazardous Distance

The hazard distances determined for the Boiling Liquid Expanding Vapor Explosion (BLEVE) scenario are 210 m, 152 m, and 92 m, corresponding to 5%, 50%, and 95% fatality probabilities, respectively. These distances underscore the substantial energy release related to this incident. The fireball, with a diameter of 180 meters and a duration of approximately 14 seconds, suggests the rapid combustion of the vessel's entire contents. This observation is consistent with empirical evidence from historical events; the 1984 LPG disaster in Mexico City, which involved multiple BLEVEs, resulted in fatality distances exceeding 300m from the plant boundary (Pietersen, 1988). At the 5% fatality boundary, the thermal radiation intensity of 29.1 kW/m² surpasses the ignition threshold for wood and produces immediate pain to unprotected skin (CCPS, 1999). This analysis affirms that the primary hazard posed by a BLEVE is not solely due to direct flame exposure but also arises from the intense thermal radiation that occurs prior to the expansion of the fireball.

In contrast, the jet fire scenario produced significantly smaller hazard distances, measuring 24.75 m, 19.55 m, and 15.5 m. This difference is attributed to the directional release and the continuous combustion of a controlled mass flow rate of 20.38 kg/s, as opposed to the instantaneous release of the entire inventory. The calculated radiation intensity at the 5% fatality boundary is 40.4 kW/m², which is higher than the corresponding BLEVE value, indicating the sustained nature of exposure and the assumed 9 second escape time. However, the confined geometry of the jet constrains its geographic extent. This observation emphasizes the necessity of evaluating not only the intensity of thermal hazards but also their geometry and duration in the context of risk assessment (Hankinson & Lowesmith, 2012).

The VCE results (22.48m, 19.90m, and 16.60m for 5%, 50%, and 95% fatality) illustrate the Multi-Energy Method's sensitivity to congestion. The assumed congested volume of 1200 m³ produced scaled distances consistent with a medium-strength explosion (overpressures of 1.13-1.8 bar). These overpressures are sufficient to cause fatal lung injury and structural collapse, confirming the VCE as a significant near-field hazard. However, the limited extent of the congested area effectively constrained the explosion's reach, highlighting why VCE consequences are often plant-specific and highly dependent on layout (van den Berg, 1985).

4.2. Implications for Risk Prioritization and Emergency Planning

The fatality estimates presented in Tables 2 and 3 offer substantial quantitative support for the prioritization of BLEVE prevention and mitigation efforts. The BLEVE phenomenon is responsible for over 95% of the total estimated fatalities, with daytime estimates varying between 109 to 158 based on different exposure assumptions. This data necessitates that emergency plans and safety management systems be designed with a focus on this worst-case, yet plausible, scenario. The contrast between daytime and nighttime fatalities, which reflects a reduction of approximately 80%, underscores the fluctuating nature of risk. This temporal variability carries significant operational consequences; thus, public warning systems, muster point designations, and the scale of medical responses should be tailored to the specific time of day (HSE, 2015).

The jet fire and (VCE), while contributing minimally to the overall fatality count in this assessment, require careful examination. Both scenarios pose immediate dangers to personnel at the site and may act as precursors to more widespread cascading failures, often referred to as domino effects. For example, a jet fire impacting the propane storage vessel could rapidly initiate the (BLEVE) scenario currently under investigation. This relationship highlights the importance of considering accident escalation in hazard assessments, a topic that has received heightened scholarly interest (Cozzani et al., 2006).

5 Conclusions

This study employed quantitative consequence modeling within a propane storage facility, identifying a clear hierarchy of hazard severity. The scenario involving Boiling Liquid Expanding Vapor Explosion (BLEVE) has been identified as the most critical, with potential fatality distances surpassing 200 meters and estimated fatalities considerably higher than those related to jet fires or vapor cloud explosions. The results provide a quantitative foundation intended to enhance the site's emergency preparedness. The principal conclusion underscores that effective risk management requires the incorporation of technical hazard analysis into practical emergency response planning. The identified hazard zones should determine evacuation radii, inform the placement of emergency assembly points, and guide the tactical approaches of external responders. Furthermore, the notable variations in consequences between day and night indicate the need for dynamic emergency plans that consider temporal changes in population exposure.

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