Appendix E:

Quantitative Risk Assessment (QRA)

Prepared by

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PROPOSED MINOR RELAXATION OF DOMESTIC PLOT RATIO AND BUILDING HEIGHT RESTRICTIONS FOR THE PERMITTED RESIDENTIAL DEVELOPMENT WITH COMMERCIAL / RETAIL USES OF THE URA MA TAU WAI ROAD/ LOK SHAN ROAD DEVELOPMENT PROJECT (KC-020), AND PROPOSED PUBLIC VEHICLE PARK

QUANTITATIVE RISK ASSESSMENT

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1.0 Introduction

1.1 Background

The Ma Tau Wai Road/ Lok Shan Road Development Project (KC-020) (the Project) was commenced by the Urban Renewal Authority (URA) on 9 August 2024 by way of a development project in accordance to Section 26 of the Urban Renewal Authority Ordinance (URAO). The Secretary for Development (SDEV) has authorised the URA to proceed with the Project without any amendment on 26 August 2025, the decision was subsequently gazetted on 5 September 2025.

Under the district-based planning approach, the Project was intended to be holistically planned and designed with the adjoining approved URA Kau Pui Lung Road / Chi Kiang Street Development Scheme (CBS-2:KC) to multiply the planning gains. The two projects may be submitted under the same land grant(s), with possibility of under different phases, for implementation.

To tally with the permissible domestic plot ratio (DPR) and building height restriction (BHR) of CBS:2-KC for holistic design and implementation, a Planning Application in accordance to Section 16 of the Town Planning Ordinance (S16 Planning Application) is required to seek Town Planning Board (TPB)'s approval on minor relaxation of DPR restriction from 7.5 to 8.0 and BHR from 120 mPD to 140 mPD for the Application Site (i.e. the area zoned "R(A)' on the OZP within the Project boundary). It is also proposed to include Public Vehicle Park (PVP) use to facilitate design flexibility for accommodating the PVP parking spaces required by CBS-2KC in the future combined development, if necessary.

The proposed relaxation in the S16 Planning Application can facilitate a more flexible layout across the two sites (i.e. the Application Site and CBS-2:KC) which are under same permissible BHR and PR controls upon this S16 approval. Nevertheless, despite that a combined development will be proposed, the URA undertakes that the portion of the future combined development within the Application Site would not exceed maximum DPR of 8.0 and total PR of 9.0.

This S16 Planning Application is a non-scheme-based submission. The notional design and indicative development parameters provided in the application are solely for illustration purpose and for conducting necessary technical assessments. Except for any planning condition(s) to be imposed, the design of the future development will not be bounded by the notional design submitted in the S16 Planning Application.

The Project is broadly bounded by Ma Tau Wai Road to the east, a back lane to the south, URA's Kau Pui Lung Road / Chi Kiang Street Development Scheme (CBS-2:KC) to the west and Lok Shan Road to the north. The application site of the subject S16 Planning Application comprises only the area zoned "Residential (Group A)" ("R(A)") within the Project boundary, excluding the adjoining area shown as "Road" on the Draft Ma Tau Kok Outline Zoning Plan No. S/K10/31 (the Application Site) (**Figure 1** refers).

The Application Site covers an area of about 1,566 m^2. Under current notional design, the Project proposes to develop one residential tower with 31 residential storeys on top of a podium for retail uses and club house. The Application Site is about 125m away from a Liquefied Petroleum Gas (LPG) Compound of Lok Man Sun Chuen (LMSC) that is located near LMSC Block G in the west of the Project. The LPG Compound has a full load capacity of 3.5 tonnes and is classified as Notifiable Gas Installations (NGIs) under the Gas Safety Ordinance (Cap. 51). A Quantitative Risk Assessment is hence prepared to address the potential risk impact posed by the LPG Compound on the population in the vicinity including the future population after the redevelopment of the Project.

1.2 Scope of Work

The scope of this study includes the LPG Compound near Block G of LMSC. The objectives are to evaluate the risk levels associated with the LPG Compound to the public, and to determine whether any additional risk mitigation measures are required in the design of the Project.

The scope of the study is limited by the following criteria:

1. The risks associated with the transport of LPG by road tankers have been restricted to the consideration of their final approach to the LPG storage installation within the LPG Compound;
2. The risk assessment has been limited to those events which have the potential for off-site fatalities.

1.3 Hong Kong Planning Standards and Guidelines (HKPSG)

1.3.1 Hong Kong Risk Guidelines

Chapter 12.4 of the HKPSG [1] stipulates the risk guidelines to determine the acceptability of Potentially Hazardous Installation (PHI) in terms of individual and societal risks. These risk guidelines are also adopted to ascertain whether or not the risk levels posed by the NGIs are acceptable.

The individual and societal risk criteria for the risk assessment are described below:

i. Individual Risk: a measure of the frequency at which an individual at a specified distance from the hazardous installations is expected to sustain a specified level of harm from the realization of hazardous incident(s). The maximum level of off-site individual risk causing fatality of a person located 24 hours a day outside the facility of concern should not exceed 1×10^{-5} / year, i.e. 1 in 100,000 per year.

ii. Societal Risk: a measure of the relationship between the frequency of an incident and the number of fatalities that will result. It is typically expressed graphically by an F-N curve showing the cumulative frequency (F) of incidents causing N or more fatalities. The societal risk criteria are presented graphically as in **Figure 2**. There are three regions as described below:

- **Acceptable** where the risk is so low that no action is necessary;
- **Unacceptable** where the risk is so high that they should be reduced regardless of the cost or else the hazardous activity should not be proceeded; and
- **ALARP** where the risk associated with the hazardous activities should be reduced to a level of "As Low As Reasonably Practicable", in which the mitigation measures should be prioritized on the basis of practicality and implementation cost versus the risk reduction achieved.

1.4 Methodology

1.4.1 Overall QRA Approach

The general approach to the QRA is represented in **Figure 3**. It follows the HKRG stipulated in Section 4 of Chapter 12 of the HKPSG [1] and the QRA Methodology for LPG Installations in Hong Kong [3]. A recent QRA study for URA's adjoining CBS-2:KC Development Scheme (namely 2020 CBS-2:KC QRA) was conducted and approved in 2020 [2]. Reference has been made to 2020 CBS-2:KC QRA.

The major phases in QRA include:

i. **Hazard Identification**: Identify hazard scenarios associated with the operation of the LPG Compound, and then determine a set of relevant scenarios to be included in a QRA.

ii. **Frequency Assessment**: Assess the likelihood of occurrence of the identified hazard scenarios.

iii. **Consequence Assessment**: Assess the consequences and impact to the surrounding population.

iv. **Risk Summation and Assessment**: Evaluate the risk level, in terms of individual risk and societal risk. The risks will be compared with the criteria outlined in HKRG to determine their acceptability.

v. **Identification of Mitigation Measures**: Identify and assess practicable and cost-effective risk mitigation measures if necessary. The risks of mitigated cases will then be reassessed to determine the level of risk reduction.

1.4.2 Case to be Considered

The Project is targeted to be completed in 2033/34 for population intake. As for conservativeness, the assessment year of this study is taken as 2 years after project completion, i.e. 2036, assuming the Project being fully occupied. This study will therefore consider following cases for the LPG Compound:

- ***Case 1 – Base Case in Year 2036:*** evaluating the risk level in year 2036 without the implementation of the Project;

- ***Case 2 – Operation Case in Year 2036***: evaluating the risk level in year 2036 with the operation of the Project at full capacity.

2.0 Description of LPG Installations

The LPG Compound at Lok Man Sun Chuen, operated by ExxonMobil Hong Kong Limited (Esso), is located near Block G of Lok Man Sun Chuen, as indicated in **Figure 1**. The LPG Compound supplies LPG as the fuel source in Lok Man Sun Chuen. As confirmed by Esso, there was no modification to the LPG Compound in the past 20 years. With reference to the 2020 CBS-2:KC QRA [2], the operation of storage and delivery of LPG at the LPG Compound are summarised in the following sections. Detailed information are included in **Annex A**.

2.1 LPG Compound at Lok Man Sun Chuen Block G

2.1.1 Existing LPG Storage Installation

The LPG Compound is surrounded by LMSC Block G is at an elevation of approximately 15.4mPD. There is a car park to the south of the LPG Compound and a playground to the north of the LPG Compound. As per 2020 CBS-2:KC QRA [2], the LPG Compound comprises an aboveground mounded vessel in the middle of the site and three explosion-proofed vaporisers in an enclosed room at the west sides of the side. The mounded vessel is of 8.2 kilolitre capacity (equivalent to 3.5 tonnes LPG inventory, taking into account the ullage requirement of not filling more than 80% of the vessel volume). The vessel is stress relieved and 100% radiographed.

2.1.2 LPG Delivery and Transfer

LPG is delivered to the LPG Compound by road tankers with a maximum capacity of the road tanker of about 9 tonnes [2]. Road tankers are assumed to be operated in accordance with the Code of Practice for Hong Kong LPG Industry – Module 3 Handling and Transport of LPG in Bulk by Road [5].

As confirmed by Esso, there is no change to the operation in the LPG Compound near LMSC Block G, an annual LPG deliveries of 220 times are adopted in this study in accordance with 2020 CBS-2:KC QRA [2]. LPG is dispensed from the tanker into the storage vessel through a loading arm.

Table 1 Summary of LPG Compound

Parameter	LPG Compound near LMSC Block G
Number of vessels	1
Mounded or Underground	Mounded
Design capacity of vessel	8.2 kilolitre
Full load capacity of vessel	3.5 tonnes
Maximum capacity of LPG road tanker	9 tonnes
LPG delivery frequency	220 per year
Duration of unloading operation	<25 min
Residence time of LPG road tanker	25 min

Parameter	LPG Compound near LMSC Block G
Number of vaporizers	3

3.0 Project Data

3.1 The Project

The Project covers an area of about 1,566m^2 on Ma Tau Wai Road and is currently zoned "Residential (Group A)". The preliminary layout of the Project is shown in **Annex B**.

The Project will provide a total of about 279 units in one residential tower on top of podium which will incorporate retail and clubhouse facilities.

The development of the Project is targeted to be completed in Year 2033/34 for population intake and is assumed to be fully occupied in 2036.

3.2 Study Area

The LPG Compound is located about 125m away in the west of the Project.

The study area for the LPG Compound is taken as 200 metres radius from centre of the LPG Compound, as shown in **Figure 1**.

3.3 Population Data

3.3.1 Population in the Vicinity

The population lie within the 200m study area of the LPG Compound may be impacted by hazardous events arising from the accidental LPG release from the LPG Compound. Population closest to the hazardous installations are most at risk. As the QRA is aimed to assess the off-site risk to life, staff present at the LPG Compound are regarded as voluntary takers of risk and are not considered in this study.

The future population within the study areas is estimated based on information collected from desktop studies. The following information and assumptions are adopted in the estimation:

- 2021 Population By-Census [6] for residential population in LMSC and surrounding street blocks;
- Conservative assumption of zero growth for residential population in Town Planning Unit (TPU) 241 instead of negative growth observed in 2021 Population By-Census [6] and the Projections of Population Distribution 2023 – 2031 [7]; and
- Maximum accommodation capacity of school as per Education Bureau's database [8].

The population groups considered in the vicinity of the LPG Compound are illustrated in **Figure 4**. The detailed population data is summarised in **Table 2**.

3.3.2 Transient Population

Transient population includes traffic population as well as pedestrians along the road sections. Traffic population can be calculated using the equation below:

$$\text{Traffic Population (ppl)} = \frac{\frac{\text{No. of ppl}}{\text{vehicle}} \times \frac{\text{No. of vehicle}}{\text{hr}}}{\text{Traffic Speed } ({}^{\text{km}}/_{\text{hr}})} \times \text{Road Section Length (km)}$$

The transient population adopted for this study is summarised in **Table 2** with the detailed calculations provided in **Annex C**.

Table 2 Population Data within Study Area in Year 2036

ID	Population Name	Population Category	Population in Year 2036		Temporal Population Change				Indoor Ratio	Ground Level (+mPD)	Building Height (+mPD)	Remarks
			Base Case	Operation Case	WDD	WDN	WED	WEN				
03	Lok Man Sun Chuen Block A&B	Residential	1092	1092	25%	100%	70%	100%	95%	20	62.2	2021 Population By-Census
04	Lok Man Sun Chuen Block C&D	Residential	1127	1127	25%	100%	70%	100%	95%	23	65.3	2021 Population By-Census
05	Lok Man Sun Chuen Block E&F	Residential	1719	1719	25%	100%	70%	100%	95%	29	66.3	2021 Population By-Census
06	Lok Man Sun Chuen Block G	Residential	2300	2300	25%	100%	70%	100%	95%	15	58.5	2021 Population By-Census
07	Celestial Heights	Residential	3310	3310	25%	100%	70%	100%	95%	30.1	150	2021 Population By-Census
08	Residential Buildings (LSBG24117)	Residential	681	681	25%	100%	70%	100%	95%	13	31	258 units. Approximated from 2055 people within LSBG24117 as per 2021 Population By-Census
09	Morning Joy Building, City 151 (LSBG24117)	Residential	626	626	25%	100%	70%	100%	95%	15	80.7	237 units. Approximated from 2055 people within LSBG24117 as per 2021 Population By-Census
10	URA CBS-2:KC Site											
	Residential Buildings	Residential	6043	6043	25%	100%	70%	100%	95%	25	140	As advised by URA
	Club House	Club House	300	300	50%	20%	100%	20%	95%	20	25	Reference to 2020 CBS-2:KC QRA
	Community Facilities	Community	240	240	100%	100%	100%	100%	95%	14	20	Reference to 2020 CBS-2:KC QRA
	Retail	Retail	770	770	50%	25%	100%	25%	95%	14	20	Reference to 2020 CBS-2:KC QRA
11	80 Maidstone Road	Residential	243	243	25%	100%	70%	100%	95%	13.2	121.9	92 units. Approximated from 2055 people within LSBG24117 as per 2021 Population By-Census
12	The Uptown	Residential	125	125	25%	100%	70%	100%	95%	12.7	111.7	48 units. Approximated by Domestic Household Size of 2.6 in TPU241
13	Mega Building, Delight Court, Mainshine Court, Goldtone Court (LSBG24118)	Residential	527	527	25%	100%	70%	100%	95%	12	66	183 units. Approximated from 1287 people within LSBG24118 as per 2021 Population By-Census
14	Residential Buildings (LSBG24118)	Residential	761	761	25%	100%	70%	100%	95%	12	30	264 units. Approximated from 1287 people within LSBG24118 as per 2021 Population By-Census
16	Planned Residential Development	Residential	266	266	25%	100%	70%	100%	95%	13.2	100.7	102 units. Approximated by Domestic Household Size of 2.6 in TPU241
18	Residential Buildings (LSBG24123-24125)	Residential	1607	1607	25%	100%	70%	100%	95%	9	44	570 units. Approximated from 2210 people within LSBG24123-24125 as per 2021 Population By-Census
35	S.K.H. Good Shepherd Primary School	School	635	635	100%	0%	10%	0%	90%	11.2	30.1	Maximum classroom accommodation capacity of 585 students. Assume 50 teachers and staffs.
36	E.L.C.H.K. Hung Hom Lutheran Primary School	School	590	590	100%	0%	10%	0%	90%	10.8	25.9	Maximum classroom accommodation capacity of 540 students. Assume 50 teachers and staffs.
37	Kau Piu Lung Road Playground	Recreational	40	40	40%	10%	100%	10%	0%	45.8	-	Conservative assumption.

ID	Population Name	Population Category	Population in Year 2036		Temporal Population Change				Indoor Ratio	Ground Level (+mPD)	Building Height (+mPD)	Remarks
			Base Case	Operation Case	WDD	WDN	WED	WEN				
PD01	Project Site:											Project information
	Existing Residential Buildings (LSBG24121)	Residential	288	0	25%	100%	70%	100%	95%	10	30	
	Residential Buildings (KC-020)	Residential	0	754	25%	100%	70%	100%	95%	34.4	140	
	Club House (KC-020)	Club House	0	21	50%	20%	100%	20%	95%	20.9	30.9	
	Retail (KC-020)	Retail	0	81	50%	25%	100%	25%	95%	10.9	20.9	
R01	Kau Pui Lung Road	Road	99	99	100%	61%	100%	61%	0%	15	-	Refer **Annex C**
R02	Lok Shan Road	Road	22	22	100%	61%	100%	61%	0%	13	-	Refer **Annex C**
R03A	Ma Tau Wai Road (NB)	Road	62	62	100%	61%	100%	61%	0%	8	-	Refer **Annex C**
R04A	Ma Tau Wai Road (SB)	Road	99	99	100%	61%	100%	61%	0%	8	-	Refer **Annex C**

3.3.3 Temporal Change in Population

To reflect the temporal changes in population within a week, the corresponding population proportion of the time periods are assumed based on observation from site survey and with reference to the 2020 CBS-2:KC QRA [2] and the approved Environmental Impact Assessment (EIA) report [9].

Day time is defined as 07:00 to 19:00 and night time from 19:00 to 07:00 next day. The temporal changes of different population category are provided in **Table 3**. The detailed temporal changes of population for each population site considered are provided in **Table 2**.

Table 3 Temporal Change of Population within a Week

Category	Time Period			
	Weekday Day (WDD)	Weekday Night (WDN)	Weekend Day (WED)	Weekend Night (WEN)
Club House (1)	50%	20%	100%	20%
Commercial (2)	100%	10%	20%	0%
Community (1)	100%	100%	100%	100%
Recreational (2)	40%	10%	100%	10%
Residential (2)	25%	100%	70%	100%
Retail (3)	50%	25%	100%	25%
Road (4)	100%	61%	100%	61%
School (2)	100%	0%	10%	0%

Note:

(1) Conservative assumption
(2) Reference to 2020 CBS-2:KC QRA [2]
(3) Reference to South Island Line EIA [9]
*(4) Estimated from Annual Traffic Census 2023. Refer **Annex C**.*

3.4 Indoor/Outdoor ratio

Building structures can offer some protection from fires for the occupants inside. An indoor ratio of 95% is applied to the population in residential buildings and commercial buildings while the remaining 5% of population is assumed to be outdoor, accounting for outdoor activities and walking pathways. Considering the outdoor activities in school, an indoor ratio of 90% is applied. Passengers in vehicles are also considered as 100% outdoors population although vehicles may provide certain protection.

3.5 Source of Ignition

Flammable gas cloud from an accidental release can be ignited and led to fire or explosion if there are ignition sources present in the close proximity or along the dispersion path of the cloud. If the gas cloud is diluted outside the flammable concentration range (i.e. below Lower Flammable Limit), or in the absent of ignition sources, no fire hazards will be expected. The energy level, timing, location and ignition effectiveness of ignition sources in the vicinity of the hazardous installations affect the extent of gas cloud dispersion and its potential impacts.

Two types of ignition sources are defined in the SAFETI model, including:

- *Population source* which are assigned implicitly to all population groups by SAEFTI to account for human activities such as smoking, cooking and using electrical appliances.

- *Transportation route segments* which are defined for the moving vehicles on roads. The ignition probability of a transportation route segment is calculated form the traffic density, average vehicle speed, vehicle ignition efficiency and total length of the road. The vehicle ignition efficiency for moving vehicles is adopted to be 0.4 per 60 second [10]. Traffic flow and average vehicle speed are included in **Annex C**.

3.6 Meteorological Information

Meteorological conditions affect the consequences of a gas release, in particular wind directions, speeds and stabilities which influence the direction and degree of turbulence of a gas dispersion. Meteorological data from the Kai Tak Weather Station (Year 2024) was collected from the Hong Kong Observatory and adopted in the consequence modelling to compute the effects of various gas dispersions, fires and explosions. The data are rationalized into a set of weather classes in accordance with the Netherlands Organisation for Applied Scientific Research (TNO) Purple Book [10]. The meteorological data can be expressed in the combinations of wind speeds and Pasquill stability classes. Pasquill classes (A to F) represent the atmospheric turbulence, in which class A being the most turbulent class while class F being the least turbulent class.

The six most dominant sets of wind speed-stability class combination for both day-time and night-time are listed in **Table 4** and **Table 5** respectively. The average ambient temperature adopted in the analysis is 25°C and relative humidity is 80%.

Table 4 Day Time Wind Direction Frequency at Kai Tak Weather Station (Year 2024)

Direction	Weather Class						Total
	3.5B	2.0D	4.0D	7.5D	3.0E	1.5F	
0 – 30	1.49	0.33	0.44	0.00	0.09	0.51	2.87
30 – 60	1.78	0.42	0.75	0.00	0.63	0.42	3.99
60 – 90	1.92	0.33	0.61	0.00	0.54	0.58	3.97
90 – 120	3.90	0.19	1.14	0.42	0.28	0.33	6.26
120 – 150	13.81	0.72	7.66	0.68	1.45	0.58	24.90
150 – 180	16.54	2.17	3.36	0.12	1.14	2.06	25.39
180 – 210	2.45	0.63	0.09	0.00	0.19	0.70	4.06
210 – 240	2.03	0.54	0.07	0.00	0.16	0.28	3.08
240 – 270	5.40	0.79	0.54	0.00	0.23	0.58	7.54
270 – 300	4.39	0.68	0.77	0.02	0.28	0.68	6.82
300 – 330	2.34	0.63	0.56	0.00	0.49	0.79	4.81
330 – 360	3.39	0.28	1.45	0.14	0.56	0.47	6.28
All	59.43	7.71	17.45	1.38	6.05	7.99	100.00

Table 5 Night Time Wind Direction Frequency at Kai Tak Weather Station (Year 2024)

Direction	Weather Class						Total
	3.5B	2.0D	4.0D	7.5D	3.0E	1.5F	
0 – 30	0.00	0.05	0.95	0.00	0.71	2.71	4.42
30 – 60	0.00	0.12	0.62	0.00	2.05	2.85	5.64
60 – 90	0.00	0.07	0.36	0.00	1.31	1.71	3.45
90 – 120	0.00	0.05	2.59	0.50	1.36	1.40	5.90
120 – 150	0.00	0.12	13.70	1.05	8.92	4.80	28.59
150 – 180	0.00	0.38	3.31	0.00	6.28	11.61	21.57
180 – 210	0.00	0.12	0.05	0.00	0.45	4.38	4.99
210 – 240	0.00	0.02	0.14	0.00	0.43	2.57	3.16
240 – 270	0.00	0.05	0.21	0.00	0.69	2.57	3.52
270 – 300	0.00	0.00	0.76	0.12	1.33	3.59	5.80
300 – 330	0.00	0.14	1.36	0.02	1.38	3.54	6.44
330 – 360	0.00	0.02	2.26	0.02	1.76	2.45	6.52

Direction	Weather Class						Total
	3.5B	2.0D	4.0D	7.5D	3.0E	1.5F	
All	0.00	1.14	26.30	1.71	26.66	44.19	100.00

4.0 Hazard Identification

4.1 Properties of LPG

LPG supplied in Hong Kong is a pressurized mixture of propane and butane (3:7 in mole ratio). Upon release to the ambient environment, it vaporises and mixes with air, forming a dense flammable gas cloud which tends to flow and disperse closed to the ground. The gas cloud may extend over a long distance until it becomes too diluted or encounters ignition sources.

4.2 Event Leading to an Accidental LPG Release

The main hazard associated with the LPG facilities is an accidental uncontrolled release of LPG resulting in a fire or explosion upon ignition. The initial events leading to an LPG release could be one of the following:

- Spontaneous failure of pressurised LPG equipment due to material / design / construction defect, fatigue, corrosion, erosion, etc.;
- Spontaneous failure of vaporiser;
- Loading failure, i.e. an LPG release occurs as a direct result of the road tanker unloading operation; and
- External events.

4.2.1 LPG Storage Vessel Failure

Failure of the LPG storage vessel includes cold catastrophic failure and partial failure (25mm hole), which may result from:

- Spontaneous failure;
- Loading failure due to overfilling / over-pressurisation of storage vessel; and
- External events, such as earthquake.

Considering the content in vessel varies in time due to consumption and refilling, the vessel is assumed nominally at full load capacity (i.e. 3.5 tonnes, 80% of maximum capacity) for 20% of time and at low inventory with 60% of full load inventory (i.e. 2.1 tonnes) for the rest of the time [4]. In case of failure of storage vessel due to overfilling, the release inventory is assumed to be 100% of maximum capacity.

4.2.2 LPG Road Tanker Failure

Failure of the LPG road tanker includes cold catastrophic failure and partial failure (25mm hole), which may be resulted from:

- Spontaneous failure; and
- Accidents during unloading caused by collision by another vehicle.

Similar to the case of storage vessel that the content of an LPG road tanker varies with time, road tanker is modelled to have full inventory for 20% of the time and 50% of inventory for the remaining 80% of time.

4.2.3 **Pipework Failure**

Spontaneous failure of the LPG pipework is possible due to materials defects, corrosion, fatigue and erosion. Most of the LPG pipework is mounted on the concrete floor/structure, which includes the liquid filling pipework for LPG unloading to the LPG storage vessel, the liquid supply line to the vaporisers and the vapour line from the LPG storage vessel to the gas regulators of the gas distribution pipework.

Pipework may fail in an earthquake, and some of the pipework may be subjected to failure due to impact of the LPG road tanker.

4.2.4 **Vaporizer Failure**

LPG from vessel is vaporized through water-heated coils in the water bath type vaporizers before supplying for consumption. Failure of coils may lead to catastrophic failure of vaporizer with its failure mode similar to a pipeline failure.

4.2.5 **Flexible Hose and Loading Arm Failure**

An accidental release from the flexible hose or loading arm may be caused by:

- Spontaneous failure; and
- Loading failures, including:
    - Misconnection error – an error where the driver / operator fails to properly connect the loading hose / loading arm and the hose / loading arm comes adrift during unloading;
    - Disconnection error – an error where the driver / operator inadvertently disconnects the hose / loading arm while the valve is still open or has failed open; and
    - Road tanker drive-away error – an error where the driver inadvertently drives the LPG road tanker away during unloading.

4.2.6 **External Events**

An LPG release may occur due to external events and the consequence could be catastrophic failure or leak. The related external events are listed as follows:

- Earthquake;
- Aircraft crash;

- Car crash;
- Landslide;
- Severe environmental events;
- Lightning strike;
- Dropped object;
- Subsidence; and
- External fire.

4.3 Safety Provisions

Various safety provisions are installed in the LPG Compound. These provisions can act in different combinations to prevent or mitigate the hazards due to an accidental LPG release.

4.3.1 Isolation System

The following safety provisions are provided on LPG road tanker and in the LPG Compound to prevent uncontrolled release of LPG:

- **Non-return valve** installed on the liquid inlet pipework can prevent back flow from the LPG storage vessel;
- **Excess flow valves** installed at the LPG road tanker and LPG storage vessel are used to stop the liquid flow when a large release occurs (e.g. guillotine failure of the pipe / hose);
- **Breakaway coupling** is installed to prevent the LPG spillage due to LPG road tanker drive-away while the hose / loading arm is still connected during unloading;
- **Double-check filler valve** is installed at the LPG filling point to prevent the release from the LPG storage vessel. The design of the valve is essentially two non-return valves in series;
- **Pressure relief valves** are installed on the LPG road tanker and LPG storage vessel to protect against excessive pressure build-up due to overfilling or over-heating by fire. The pressure relief valve can prevent the excessive pressure causing leak or catastrophic failure of the LPG road tanker / LPG storage vessel;
- **Manual isolation valves** are installed on the LPG road tanker and pipework for operator / drivers to isolation LPF installations in case of failure or for maintenance operation; and
- **Emergency shutdown (ESD) system** on the LPG road tanker isolates the tanker and stops unloading operation when activated.

4.3.2 Firefight / Fire Protection

The following detection and firefighting systems are implemented in the LPG road tanker and LPG Compound to mitigate the hazards of accidental LPG release:

- **Chartek coating** on the LPG road tanker could give a protection and prevents formation of hot spots for at least 30 minutes in case of jet fire impingement [3].
- **Fire service protection system** includes dry powder fire extinguishers and sand buckets are provided for general firefighting uses. Fire brigade will be available within a few minutes upon an emergency call in case of fire. BLEVE events could be prevented by effective firefighting measures by the well-trained firefighters.

4.4 Outcome of an Accident LPG Release

The following outcomes may result from an accidental LPG release:

- Jet fire;
- Flash fire;
- Vapour cloud explosion (VCE);
- Fireball; and
- Boiling Liquid Expanding Vapor Explosion (BLEVE).

Potential fire escalation to a BLEVE event is considered if a jet fire impinges on the LPG road tanker over a period of time, causing the formation of hot spots on the LPG road tanker wall and subsequent structural failure. Storage vessel in the LPG Compound is mounded in a concrete compartment filled with washed sand. Escalation to BLEVE is considered unlikely for the LPG storage vessels.

If there is no ignition source in the LPG vapour cloud or along the migration path of the cloud with the wind, the LPG vapour cloud will dissipate and cause no hazardous impact.

4.5 LPG Release Scenarios Considered

Representative LPG accidental release scenarios considered in this study are summarized in **Table 6.**

Table 6 Representative LPG accidental release scenarios considered

Equipment	Failure Type	Release Type	Potential Hazardous Outcomes
LPG Storage Vessel	Catastrophic failure	Instantaneous	Fireball, flash fire
	Partial failure (leak)	Continuous	Jet fire, flash fire
LPG Road Tanker	Catastrophic failure	Instantaneous	Fireball, flash fire
	Partial failure (leak)	Continuous	Jet fire, flash fire

Equipment	Failure Type	Release Type	Potential Hazardous Outcomes
Vessel Filling Line	Guillotine failure	Continuous	Jet fire, flash fire, BLEVE (1)
Supply Line to Vaporiser	Guillotine failure	Continuous	Jet fire, flash fire
Vaporiser	Guillotine failure (of vaporiser coil)	Continuous	Jet fire, flash fire
Loading Arm	Guillotine failure	Continuous	Jet fire, flash fire, BLEVE (1)

Note:

(1) BLEVE of LPG road tanker

5.0 Frequency Assessment

A frequency assessment involves analysis of likelihood of LPG containment failure leading to an accidental LPG release and subsequent outcome probabilities. The initiating failure probabilities are estimated from the historical accident statistics, published failure data report, industrial testing results and expert judgment. Base failure frequencies of LPG facilities (vessels, pipework, etc.) are derived from the initiating failure events by applying failure analysis techniques such as fault tree analysis. Occurrences of subsequent hazardous outcomes in an accident are estimated by event tree analysis, taking severity of the release event and surrounding environment into account.

5.1 Spontaneous Failure

5.1.1 LPG storage vessel failure

Storage vessel failure refers to cold catastrophic failure leading to instantaneous release of the inventory or cold partial failure causing a continuous leak. Failure rates of 1.8×10^{-7} per vessel year and 5.0×10^{-6} per vessel year are adopted for cold catastrophic and partial failures respectively, and a modifying factor of 2 is applied to the spontaneous failure rates of LPG vessel as the vessel was constructed over 20 years ago [3].

5.1.2 LPG road tanker failure

LPG road tanker can be regarded as a mobile LPG storage vessel. The cold spontaneous failure rate for LPG road tankers is considered to be higher than that for a fixed storage vessel. This is because of the stresses due to vibration during transportation, and cyclic loading associated with filling/unloading of the road tanker. The catastrophic and partial failure probabilities of an LPG road tanker are assumed to be 2.0×10^{-6} and 5.0×10^{-6} per year [3], respectively.

5.1.3 Pipework failure

Failure of LPG pipework can be guillotine failure (full-bore rupture) and partial failure (leak from pipe cracks). The generic guillotine failure rate of LPG pipework is taken as 1.0×10^{-6} per meter per year [3]. Pipework in the LPG Compound are of small diameters which are less than 50mm, leak from pipework is considered insignificant contributors to the overall risk levels. The failure of pipework may result in uncontrolled continuous release of LPG, if and only if, isolation fails, i.e. simultaneous failure of safety equipment (e.g. non-return valve, excess flow valve) and safety actions (e.g. close of manual shut-off valves, activation of ESD system).

5.1.4 Vaporiser failure

LPG from the storage vessel is vaporised in the water-heated coils of the vaporisers. The fluid flowing through the heating coil is of two-phase. Guillotine failure of the coils is conservatively regarded as liquid release. Failure rate of vaporiser is taken as 1.0×10^{-6} per meter per year [3] for the coil failure, giving a failure frequency of 5.0×10^{-6} per year for an average coil length of 5 m.

5.1.5 Flexible hose and loading arm failure

Cold spontaneous failure of flexible hose and loading arm may occur during the road tanker unloading operations. Likelihood of a guillotine failure of flexible hose is taken as 9.0×10^{-8} per hour [3]. Failure rate of loading arm is considered at 10% of that of flexible hose, i.e. 9.0×10^{-9} per hour [3].

5.2 LPG Road Tanker Unloading Failure

5.2.1 Hose misconnection error

A misconnection error may occur if the hose is improperly connected to the filling point, including failure to open manual isolation valves prior to unloading operation. A likelihood of 3.0×10^{-5} per operation [3] is adopted. It is assumed that such error results in hose coming completely apart, leading to a full-bore release.

5.2.2 Hose disconnection error (during tanker unloading)

Hose disconnection error refers to inadvertently disconnecting the filling hose during the unloading operation, which requires a complete disregard of normal operating procedures, as well as the failure to re-tightening the coupling immediately upon loosening it. A gross human error of 2.0×10^{-6} per operation [3] is adopted in this study.

5.2.3 Disconnection with valve open

A release may ensue when the hose is disconnected if isolating valves are left open or fail to close. This event is considered insignificant because it involves failure of a series of safety valves (non-return valve, and double-check filler valve), in additional to failure of the driver and his assistant to close the manual shut-off valve.

5.2.4 Road tanker drive-away error

A drive-away error may occur due to repositioning of the truck during delivery. The outcome of this failure matches that of hose disconnection, i.e. full-bore release. Repositioning during delivery is deemed remote because the road tanker should be parked in a dedicated unloading bay with an implementation of numerous safety measures such as the use of wheel chocks, interlocks on shutters and parking brake. The operators are responsible for monitoring the unloading process during replenishment. Thus, the probability of drive-away error before operation completion is deemed very low and a failure rate of 4.0×10^{-6} per operation [3] is adopted.

5.2.5 Road tanker impact onto LPG facilities

The road tanker may strike the LPG installation during manoeuvring, causing damage to the LPG installation or the road tanker. A likelihood of 1.5×10^{-4} per operation [3] is adopted for this human error.

In view of the slow speed of road tanker during manoeuvring to its unloading bay, a release from the road tanker due to slight impact is considered remote because the road tanker is equipped with side and rear end protection (mechanical barriers & rear protection bumper) for the vessel, fittings, valves and pipework fitted to it.

The probability of damaging the pipework near the loading bay is considered very low in consideration of the low momentum of road tanker manoeuvring in slow speed. The probability of guillotine failure of pipework is assumed as 0.001. Furthermore, pipework close to the unloading bay in the LPG Compound are protected concrete shelf or concrete kerb which further minimise the chance and energy of direct tanker impact on the pipework. The probability for the concrete shelf / kerb failing to stop the tanker leading to guillotine failure of the pipework is assumed as 0.1. A release of road tanker's LPG content from the damaged pipework could ensue only if the driver neglects his duty to check the pipework integrity and possible leakage before unloading starts.

5.2.6 Road tanker collision during unloading

The LPG road tanker parks in a designated unloading bay inside the LPG Compound, which located at the end of access road / parking area. Given that road tanker must park into the LPG Compound by back-in, the vessel of road tanker is surrounded by fence. The chance of a vehicle having sufficient impact force to damage the fence and the vessel of LPG road tanker inside is deemed remote. Nevertheless, a frequency of 1×10^{-8} per operation for the event of road tanker collided by another vehicle is adopted in accordance to the QRA Methodology for LPG Installations in Hong Kong quoted [3]. Such failure may result to catastrophic rupture at a probability of 1×10^{-4} or partial failure at a probability of 1×10^{-3}.

5.2.7 Loading pipework over-pressurisation

In an unloading operation, the operator may make an error that fails to open all valves on the filling line to the storage vessel, which would potentially result in over-pressurization of the loading pipework. This potential scenario is considered under "Misconnection error".

5.2.8 Storage tank overfilling/ over-pressurisation

As usual on-site practice of LPG unloading operation, the vessel should only be filled up to 80% of the total capacity. The filling in progress should be monitored by the operators through the ullage gauge at all time. The possibility of overfilling is deemed low and is taken to be 2.0×10^{-2} per operation [3]. However, even if overfilling occurs, an LPG release due to over-pressurisation will only happen if the following human error or failure of safety provisions take place:

- Operators fail to activate ESD system;
- Failure truck pump over-pressurization protection system; and
- Failure of pressure relief valve on the storage vessel.

The chances of overfilling escalating to catastrophic rupture and partial failure of storage tank are assumed as 0.1 and 0.01, respectively.

5.2.9 Human Error

In case of accidental failure, it is very probable that the onsite staff can rectify the problem before and after any hazard event occurs. Two competent operators are required to be engaged in the unloading process and stayed in close vicinity to the road tanker and the filling point during the unloading. They are suitably trained in unloading operation, first aid, firefighting and emergency response. Nevertheless, they might make errors in a series of operations. The probability is taken as 0.01 for "error in a routine operation where care is required" from "A Guide to Practical Human Reliability Assessment" [11].

Probability of human error becomes much higher under emergency situations when a hazard event occurs. The chance of failure to rectify the problem under extreme stresses is taken to be 0.3 for general rate of errors involving very high stress level [11].

Upon an accidental LPG release during unloading operation, the operators should immediately activate the ESD system on the tanker to terminate the unloading process and close the isolation valves. The human error to start the ESD system under an emergency situation is taken as 0.1 for failure to act correctly at a stressful emergency situation [11].

5.2.10 Failure of Safety Provision

Hazards from an accidental LPG release can be prevented or mitigated by the safety provisions at the Station. Fire protection / firefighting systems are provided at the LPG installation and on road tanker. The failure probabilities of safety provisions and fire protection system adopted are listed in **Table 7**.

5.3 External Event

5.3.1 Earthquake

Hong Kong is not located within the seismic belt. According to Hong Kong Observatory, earthquakes occurring in the circum-Pacific seismic belt which passes through Taiwan and Philippines are too far away to affect Hong Kong significantly. Moreover, buildings and infrastructures in Hong Kong are designed to withstand earthquakes up to Modified Mercalli Intensity (MMI) VII. Therefore, it is assumed that MMI VIII is of sufficient intensity to cause damage to specially designed structures. The chance of earthquake occurring at MMI VIII and higher in Hong Kong is very low in comparison with other regions and is estimated to be 1.0×10^{-5} per year [3]. It is assumed that such earthquake may result in vessel leakage and pipework rupture at a probability of 0.01 [12].

5.3.2 **Aircraft crash**

The LPG Compound is far away from the Hong Kong International Airport with a distance of about 27 km. The frequency of aircraft crash is estimated using the HSE methodology. The frequency of aircraft crash is estimated using the HSE methodology [13] and the estimated number of flights predicted from air traffic statistics between year 2014 and 2024 [14]. The calculated rate of aircraft crash to the LPG Compound is 8.6×10^{-12} per year, which is less than 1.0×10^{-9} per year, and therefore, aircraft crash is not further considered.

5.3.3 **Car crash**

No entry of unauthorised vehicle is allowed in the LPG Compound. The LPG Compound is separated from the car park by concrete wall. Only minor car accident might be expected at the sites, which is considered to impose negligible threat to the LPG installation. This risk is deemed to be included in the "Road tanker collision during unloading".

5.3.4 **Landslide**

Landslide may damage the LPG installation. Since there is no slope feature near the LPG store, landslide risk is not further considered.

5.3.5 **Severe environmental events**

Loss of containment due to severe environmental events such as typhoon or storm surge (large scale tidal wave) is considered unlikely since the LPG vessels are either buried underground or mounded in a concrete compartment filled with washed sand. The LPG installation is designed safe to withstand the wind load for typhoon. In case of super typhoons observed in recent years, no major loss of containment incident had been reported in the LPG Compound. Therefore, the risk of LPG release due to severe environmental events is deemed unlikely and not further considered in the analysis.

5.3.6 **Lightning strike**

The frequency of lightning strike on a properly protected building structure is extremely low in Hong Kong. Risk resulting from lightning strike on facilities in the LPG Compound is extremely low as the compound is fitted with lightning rod and surrounded by a number of high-rise buildings. It is deemed lightning strike is remote, therefore not further considered in the analysis.

5.3.7 **Dropped object**

The LPG Compound is surrounding by LMSC Block G in a separation distance of at least 4m. Most of installations in the LPG Compound near LMSC Block G is covered by concrete cover. It is expected that any dropped object fall on the LPG installations can only cause neglectable effect. In addition, the LPG Compound is fenced by concrete wall and wired fence which prevent object in projectile motion falling into LPG Compound. Therefore, it is considered the threat from dropped objects is remote and not further assessed in the analysis.

5.3.8 Subsidence

Excessive subsidence may lead to failure of the structure and ultimately loss of containment scenario. However, subsidence is usually slow in movement and such movement can be observed and remedial action can be taken in time. Risk from subsidence is therefore deemed remote and not further considered.

5.3.9 External fire

External fire refers to the occurrence of a fire event outside the LPG Compound which may lead to the failure of the LPG facilities. This might occur from minor vehicle accidents on the private access road / outdoor car park, probably involving engine failures (e.g. overheating during hot summer). The resulting fire is usually small, only affecting a few meters around the car, and could be quickly extinguished using fire extinguishers or by the fire brigade. The key facilities inside LPG Compound are further protected by concrete building structures (e.g. the LPG vessel compartment). The risk of escalation of external fire to the LPG facilities is deemed negligible and not further considered.

5.4 Failure Frequencies

Fault Tree Analysis (FTA) was performed based on the initiating events as described above. The analysis derived a number of loss of containment scenarios that will lead to the release of LPG to the atmosphere. The failure rates adopted in the Fault Tree are summarized in **Table 7**. The Fault Trees are listed in **Annex D** and the derived frequencies of loss of containment scenarios are summarized in **Table 8**.

Table 7 Failure Rate and Probabilities Adopted

Item		Failure Rate	Unit	Remark
Spontaneous Failure				
LPG storage vessel failure	Catastrophic	1.8×10^{-7}	per vessel per year	[3]
	Partial	5.0×10^{-6}	per vessel per year	[3]
LPG storage vessel failure modification factor		2		[3]
LPG road tanker failure	Catastrophic	2.0×10^{-6}	per vessel per year	[3]
	Partial	5.0×10^{-6}	per vessel per year	[3]
Pipework failure	Guillotine	1.0×10^{-6}	per metre per year	[3]
Vaporiser failure	Guillotine	1.0×10^{-6}	per metre per year	[3]
Flexible hose failure	Guillotine	9.0×10^{-8}	per hour	[3]
Loading arm failure	Guillotine	9.0×10^{-9}	per hour	[3]
LPG Road Tanker Unloading Failure				
Hose / loading arm misconnection error		3×10^{-5}	per operation	[3]
Hose / loading arm disconnection error		2×10^{-6}	per operation	[3]
Road tanker drive-away		4×10^{-6}	per operation	[3]
Road tanker impact onto LPG installations		1.5×10^{-4}	per operation	[3]

Item		Failure Rate	Unit	Remark
Vehicle impact onto road-tanker		1×10^{-8}	per operation	[3]
Overfilling / over-pressurisation		2×10^{-2}	per operation	[3]
External Event				
Earthquake (above MMI VII)		1×10^{-5}	per year	[3]
Failure of Safety Provision				
Pressure relief valve failure		1×10^{-2}	per demand	[15]
Non-return valve failure		0.013	per demand	[3]
Excess flow valve failure (on vessel)		0.13	per demand	[3]
Excess flow valve failure (on tanker)		0.013	per demand	[3]
Emergency Shutdown (ESD) system fails		1×10^{-4}	per demand	[3]
Tank truck pump overpressure protection system failure		1×10^{-4}	per demand	Assume same as ESD system fails
Breakaway coupling failure		0.013	per demand	[3]
Double-check valve failure		2.6×10^{-3}	per demand	[3]
Human Error				
Fail to close manual valve		0.5	per demand	[3]
Fail to rectify the problem in routine check prior to unloading		0.01	per demand	[11]
Fail to activate ESD system		0.1	per demand	[11]
Fail to rectify the problem (under high stress)		0.3	per demand	[11]
Fire Protection / Fighting System Failure				
Protective fire coating failing to prevent BLEVE		0.1	per demand	[3]
Fire services failing to prevent BLEVE		0.5	per demand	[3]
Failure Probabilities				
Failure of LPG vessel due to overfilling	Catastrophic	0.01		[2]
	Partial	0.1		[2]
Failure of road tanker due to vehicle impact	Catastrophic	1×10^{-4}		[2]
	Partial	1×10^{-3}		[2]
Guillotine failure of pipework due to road tanker impact		1×10^{-3}		[2]
Guillotine failure of liquid supply vaporiser coil due to overfilling		0.5		[2]
Guillotine failure of pipework due to earthquake		0.01		[12]

Table 8 Failure Frequencies of Scenario Considered for LPG Compound

<table>
<tr><th>Fault Tree</th><th colspan="2">Hazardous Event
(Loss of Containment Scenario)</th><th>Base Frequency (per year)</th><th>Inven-tory Level</th><th>Time Fraction</th><th>Factored Frequency (per year)</th><th>Inven-tory Level</th><th>Time Fraction</th><th>Factored Frequency (per year)</th><th>Event Tree No.</th></tr>
<tr><td rowspan="2">1</td><td colspan="2">Cold Catastrophic Failure of LPG Vessel
(Spontaneous Failure and External Event)</td><td rowspan="2">3.62E-07</td><td>100%</td><td>0.2</td><td>7.20E-08</td><td>60%</td><td>0.8</td><td>2.88E-07</td><td>ETA 1</td></tr>
<tr><td colspan="2">Cold Catastrophic Failure of LPG Vessel
(Loading Failure)</td><td>Max</td><td>1</td><td>2.20E-09</td><td></td><td></td><td></td><td>ETA 1</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">Cold Partial Failure of LPG Vessel
(Spontaneous Failure and External Event)</td><td rowspan="2">1.01E-05</td><td>100%</td><td>0.2</td><td>2.02E-06</td><td>60%</td><td>0.8</td><td>8.08E-06</td><td>ETA 2</td></tr>
<tr><td colspan="2">Cold Partial Failure of LPG Vessel
(Loading Failure)</td><td>Max</td><td>1</td><td>2.20E-08</td><td></td><td></td><td></td><td>ETA 2</td></tr>
<tr><td>3</td><td colspan="2">Cold Catastrophic Failure of LPG Road Tanker</td><td>2.11E-08</td><td>100%</td><td>0.2</td><td>4.23E-09</td><td>50%</td><td>0.8</td><td>1.69E-08</td><td>ETA 1</td></tr>
<tr><td>4</td><td colspan="2">Cold Partial Failure of LPG Road Tanker</td><td>5.45E-08</td><td>100%</td><td>0.2</td><td>1.09E-08</td><td>50%</td><td>0.8</td><td>4.36E-08</td><td>ETA 2</td></tr>
<tr><td>5a</td><td rowspan="2">Guillotine Failure of Vessel Filling Line</td><td>Release from Vessel</td><td>2.44E-07</td><td>100%</td><td>0.2</td><td>4.88E-08</td><td>60%</td><td>0.8</td><td>1.95E-07</td><td>ETA 3</td></tr>
<tr><td>5b</td><td>Release from Tanker</td><td>1.38E-10</td><td>100%</td><td>0.2</td><td>2.76E-11</td><td>50%</td><td>0.8</td><td>1.10E-10</td><td>ETA 3</td></tr>
<tr><td>6</td><td colspan="2">Guillotine Failure of Supply Line to Vaporiser</td><td>1.05E-06</td><td>100%</td><td>0.2</td><td>2.11E-07</td><td>60%</td><td>0.8</td><td>8.42E-07</td><td>ETA 4</td></tr>
<tr><td rowspan="2">7</td><td colspan="2">Failure of Vaporiser
(Spontaneous Failure and External Event)</td><td rowspan="2">1.98E-06</td><td>100%</td><td>0.2</td><td>3.93E-07</td><td>60%</td><td>0.8</td><td>1.57E-06</td><td>ETA 5</td></tr>
<tr><td colspan="2">Failure of Vaporiser
(Loading Failure)</td><td>100%</td><td>1</td><td>1.43E-08</td><td></td><td></td><td></td><td>ETA 5</td></tr>
<tr><td>8a</td><td rowspan="2">Guillotine Failure of Loading Arm</td><td>Release from Vessel</td><td>3.59E-08</td><td>100%</td><td>0.2</td><td>7.18E-09</td><td>60%</td><td>0.8</td><td>2.87E-08</td><td>ETA 3</td></tr>
<tr><td>8b</td><td>Release from Tanker</td><td>1.38E-06</td><td>100%</td><td>0.2</td><td>2.76E-07</td><td>50%</td><td>0.8</td><td>1.11E-06</td><td>ETA 3</td></tr>
</table>

5.5 Event Tree Analysis

Event tree analysis (ETA) is used to develop the evolution of a failure event from its initial release to the final outcome scenarios, namely, jet fire, flash fire, fireball, etc. It depends on numerous factors such as release type (instantaneous or continuous), ignition sources and probabilities, and degree of congestion. The event tree analysis is outlined in **Annex E**. The event tree adopted for each loss of containment scenario is indicated in **Table 8**.

SAFETI's built-in event trees are used to calculate the frequencies of hazardous outcome scenarios.

5.5.1 Catastrophic Failure of LPG Storage Vessel / Road Tanker

Large releases are assumed to have a probability of 0.9 for immediate ignition [3]. The immediate ignition of instantaneous LPG release from LPG storage vessel / road tanker will result in a fireball as the content will be instantly released to the ambient.

A delayed ignition may produce a flash fire or vapour cloud explosion (VCE). A past analysis determined that the maximum overpressure obtained from VCE arising from LPG installations on public housing estates in Hong Kong would be too low to contribute significant structural damage to buildings [3]. Hence a delayed ignition is assumed to be resulted in flash fire only.

5.5.2 Partial Failure of LPG Storage Vessel / Road Tanker

A lower probability of 0.05 is adopted for immediate ignition of partial failure (leak) of LPG storage vessel and road tankers [3]. Immediate ignition of a continuous pressurized release results in a jet fire. Delayed ignition of small release is assumed at a probability of 20%, resulting in a flash fire [3].

5.5.3 Failure of Pipework / Vaporiser / Hose / Loading Arm

The probabilities of immediate ignition and delayed ignition of guillotine failure of pipework, vaporiser, hose and loading arm taken as same as that of partial failure of LPG storage vessel and road tanker.

A jet flame from guillotine failure of aboveground installations may impinge on road tanker leading to BLEVE of tanker over a period of time. The probability of flame impingement from outdoor pipework, hose and loading arm is assumed as 0.01.

The supply line to vaporiser and also the vaporisers are separated from the unloading bay by the mounded vessel in between. Jet flame from supply line and vaporisers towards the east will be blocked by the mounded vessel and is considered impossible to reach the road tanker. Besides, the mounded vessel is enclosed in a concrete chamber which offers thermal insulation against BLEVE. Hence, escalation of flame impingement from supply line and vaporisers in LPG Compound is not further considered.

LPG road tankers are protected by a layer of Chartek coating preventing the formation of hot spots. Credit is given to the passive Chartek coating protection and fire-fighting services in the LPG Compound. The probability of coating failure is assigned as 0.1 [3].

Fire services system is assumed to have a chance of 0.5 [3] being ineffective in preventing a BLEVE.

6.0 Consequence Analysis

The consequence assessment estimates impact of each outcome in the area of concern. The consequence assessment consists of two major parts, namely:

- Source term modelling – to determine the appropriate discharge models to be used for calculation of the release rate, duration and quantity of the release; and
- Physical effect modelling – to determine the gas dispersion, fire and explosion effects zone based on the output of source term modelling.

The simulation software SAFETI 8.9 developed by Det Norske Veritas (DNV) was employed to calculate the hazardous release and effects zones.

6.1 Source Term Modelling

LPG is modelled as a mixture of 30% propane and 70% butane. LPG stored in a tank is pressurised to medium pressure to reach an equilibrium state between the liquid and vapour phases, depending on the ambient temperature.

The maximum capacity of the LPG storage vessel is 8.2kL (approximately 4.4 tonnes). The vessel is assumed nominally at full load inventory (i.e. 80% of maximum capacity, equivalent to 3.5 tonnes) for 20% of the time and at low inventory level with 60% of full load inventory (equivalent to 2.1 tonnes) for the rest of the time. Road tankers are assumed to have a maximum capacity of 9 tonnes. The road tanker is modelled to have full inventory for 20% of the time and 50% of inventory for the remaining 80% of time.

Instantaneous release of the inventory is assumed for the cases of catastrophic failure. Partial failure or full bore rupture of pipework will lead to a continuous release, in which, discharge rate is calculated by SAFETI based on the leak size, release temperature, release pressure, and fluid phase. Duration of continuous discharge is determined by discharge rate and total inventory.

6.2 Physical Effect Modelling

6.2.1 Gas Dispersion

LPG vaporises rapidly and forms a vapour cloud upon release. Fire scenarios of different kinds may be developed in the presence of ignition sources in the proximity of an LPG release. If no ignition source exists, the vapour cloud will disperse downwind and will then be diluted to a concentration below its Lower Flammable Limit (LFL). In this case, the vapour cloud will become too lean to be ignited and will have no harmful effect.

The dispersion characteristics of the vapour cloud are influenced by meteorological conditions and material properties, such as density. The built-in UDM model in DNV SAFETI is used for modelling the dispersion of unignited vapour cloud following an LPG release. The model takes into account various transition phases, from dense cloud dispersion to buoyant passive gas dispersion, in both instantaneous and continuous releases.

6.2.2 Jet Fire

When flammable fluid stored under pressure releases from an orifice, it will lead to a flame jet (i.e. jet fire) if it is ignited immediately. The flame length is determined from the momentum of the release. If a jet fire impinges on another pressurised LPG storage container, thermal intrusion and heat radiation could boil liquid and induce over-pressurisation and subsequent rupture of the container, causing a BLEVE.

6.2.3 Fireball and BLEVE

Immediate ignition of an instantaneous release of massive inventory inside a pressurised vessel will result in a fireball. A fireball is characterised by its high thermal radiation intensity and short duration time. The principal hazard of fireball arises from thermal radiation, which is not significantly influenced by weather, wind direction or source of ignition.

A BLEVE occurs as fire escalation event upon integrity failure from fire impingement. It has similar characteristics to a fireball and its physical effects are calculated as a fireball.

6.2.4 Flash Fire

An LPG release, if not ignited immediately, would vaporise and form a vapour cloud around the release source. This cloud would move in the downwind direction, entraining air as it disperses and get diluted. If it gets ignited before it is diluted to below its LFL, a flash fire would result.

Major hazards from flash fire are thermal radiation and direct flame contact. Since the flash combustion of a gas cloud normally lasts for a short duration, thermal radiation effect on people near a flash fire is limited.

6.2.5 Thermal Radiation

The major hazard of a jet fire, pool fire or fireball is the flame and the thermal radiation. Persons caught in the flame zone are considered be fatally injured. Persons outside the flame zone are determined by lethal probability using the following Probit equation [10]:

$$Pr = -36.38 + 2.56 \ln Q^{4/3}t$$

where Q is the thermal radiation intensity in W/m^2 and t is the exposure time in seconds.

6.2.6 Vapour Cloud Explosion

If the vapour cloud passes through a congested area (e.g. cluster of pipe racks, a confined space) and be ignited, the confinement will limit the expansion of the burning cloud, causing an explosion and damage to the surroundings by the resulting overpressure. In SAFETI, the hazardous effects are modelled by two concentric circular areas corresponding to heavy and light building damage, respectively. Fatality rates for persons outdoors and indoors are determined from the TNO Purple Book [10].

6.3 Hazard Impacts on Offsite Population

6.3.1 Worst Consequence Distance

Population in the vicinity of the LPG Compound can be potentially affected by the hazardous events depending on the consequence distances. The affected distances of different hazardous events are simulated in SAFETI and the worst impact distances are summarised in **Table 9**.

Table 9 Summary of Worst Consequence Distances

Hazardous Event	Failure Scenario	Characteristics	Distance (m)
Fireball	Cold Catastrophic Failure of LPG Vessel	Fireball radius Lift off height	43.4 86.7
BLEVE	BLEVE of LPG Road Tanker	Fireball radius Lift off height	60.3 120.6
Jet fire	Guillotine Failure of Vessel Filling Line	Flame length Thermal Radiation at 12.5kW/m^2 (1)	24.3 35.9
Flash fire	Cold Catastrophic Failure of LPG Road Tanker	Flash fire envelop at 100% LFL	164
	Cold Catastrophic Failure of LPG Vessel	Flash fire envelop at 100% LFL	131

Note:

(1) A level of 12.5 kW/m^2 is selected for reporting purpose. According to DNV/Statoil 2001, exposure to 12.5 kW/m^2 radiation for 20 seconds corresponds to 1% fatality.

The worst consequence of flammable vapour cloud resulting from an instantaneous rupture of an LPG road tanker may drift downwind up to 165 m at high wind speeds though the vapour cloud is very likely to be ignited during its migration across ignition sources such as moving vehicles and various human activities. The LPG vapour cloud can reach up to 27m high in close proximity to the LPG Compound and gradually decrease when the vapour cloud drift downwind.

6.3.2 Indoor Protection Factor

Buildings are assumed to offer protection to occupants against fire and allow reduction in duration of exposure due to escape action of individual. In an event of flash fire, humans who are outdoor encompassed by the flash fire would be fatally injured. A fatality rate of unity is assumed for outdoor population, and 90% protection factor is assumed for indoor occupants [3]. In case of fireball event, a protection factor of 50% is assumed for indoor population within fireball radius [3].

6.3.3 Shielding Factor

Shielding factors are assumed to account for protection by the front part of the building or by other buildings from fireball effects [3]. A shielding factor of 0.5 is assigned to those buildings wholly within the fireball diameter and partly inside the fireball diameter, i.e. 60.3 m of the LPG Compound. Buildings that are outside the fireball or are not in the direct line of sight of the LPG Compound are considered being protected by the buildings in the front.

6.3.4 Height Protection Factor

Population above the cloud height is not exposed to flash fire events. In another term, these population are "protected". The height protection factors to the "protected" population are corresponding to the proportion of building above the top of the cloud [3]. The LPG Compound is located at an elevation of approximately 15.4mPD. Since the LPG Compound is on gentle slopes, the height difference between the LPG Compound and the offsite population is considered in the height protection factor.

The protection factors applied to various population groups within flash fire envelope for flash fire events are shown in **Table 10**.The height protection factor is used as a discount factor to the population of the area to address those who are not affected by the flashfire. It also applies to the jet fire scenario since the flame length of the jet fire is similar and does not exceed the cloud height of flash fire.

Table 10 Height Protection Factor Considered

ID	Description	Shielding Factor	Distance from the Compound (m)	Cloud Height	Height Protection Factor
03	Lok Man Sun Chuen Block A&B	1	188	5	0.99
04	Lok Man Sun Chuen Block C&D	1	123	5	1.00
05	Lok Man Sun Chuen Block E&F	0.5	46	9	1.00
06	Lok Man Sun Chuen Block G	0.5	16	16	0.62
07	Celestial Heights	1	73	7	1.00
08	Residential Buildings (LSBG24117)	0.5	58	8	0.42
09	Morning Joy Building, City 151 (LSBG24117)	0.5	50	9	0.86
10	URA CBS-2:KC Site				
	• Residential Buildings	1	73	7	1.00
	• Club House	1	73	7	0.52
	• Community Facilities	1	73	7	0.00
	• Retail	1	73	7	0.00
11	80 Maidstone Road	1	73	7	0.92

ID	Description	Shielding Factor	Distance from the Compound (m)	Cloud Height	Height Protection Factor
12	The Uptown	1	170	5	0.92
13	Mega Building, Delight Court, Mainshine Court, Goldtone Court (LSBG24118)	1	182	5	0.84
14	Residential Buildings (LSBG24118)	1	111	5	0.53
16	Planned Residential Development	1	118	5	0.92
18	Residential Buildings (LSBG24123-24125)	1	140	5	0.67
35	S.K.H. Good Shepherd Primary School	1	180	5	0.51
36	E.L.C.H.K. Hung Hom Lutheran Primary School	1	188	5	0.36
PD01	Project Site				
	• Existing Residential Buildings (LSBG24121)	1	125	5	0.48
	• Residential Buildings (KC-020)	1	125	5	1.00
	• Club House (KC-020)	1	125	5	1.00
	• Retail (KC-020)	1	125	5	0.05

7.0 Risk Assessment

Risk summation combines the likelihood and consequence of hazardous event, as well as meteorological data and population in the hazard effect zones, to give a numerical measure of risks around the Station. The risk analysis is conducted by the simulation software – DNV SAFETI v8.9 developed by DNV and the outcome results are presented in terms of IR contours and SR (as F-N curves or Potential Loss of Life (PLL)). The risk outcomes are compared to the criteria set out in the risk guidelines, as specified in **Section 1.3.1**.

7.1 Results of LPG Compound

7.1.1 Individual Risk Result

The individual risk contours of the LPG Compound are presented **Figure 5**. The offsite individual risk is less than 1×10^{-5} per year and satisfies with the criterion stipulated in the HKRG. The individual risk level is less than 1×10^{-9} per year at the Project site and thus, the criteria set in Hong Kong Risk Guidelines is satisfied.

7.1.2 Societal Risk Result

The societal risk results of the LPG Compound are presented in the form of F-N curve in **Figure 6** with detailed data presented in **Table 12**. The societal risk levels of the LPG Compound of both base case and operation case lie in ALARP region of the HKRG. Mitigation measure(s) is required to reduce the risk level as low as reasonably practicable.

Societal risk can also be represented in the form of Potential Loss of Life (PLL). It expresses the risk to the population as a whole and for each scenario and its location. The PLL is an integrated measure of societal risk obtained by summing the product of each F-N pair:

$$\mathrm{PLL} = f_1N_1 + f_2N_2 + \cdots + f_nN_n$$

The PLL values of the LPG Compound for both cases are presented in **Table 11**. With the additional population of the Proposed Development, insignificant change to the overall risk level of the LPG Compound is generated. The major risk contributing event at the Project is fireball arising from LPG Vessel and LPG Road Tanker.

The Site is about 125m away from the LPG Compound. Furthermore, it is worth to note that the preliminary design of the Project comprises of the residential towers on a podium of about +34.4mPD at height. Residential tower is lifted above vapour cloud released from rupture of LPG vessel. The lower floors are designed to be car park, retail, clubhouse and E&M uses, which have relatively low population density in compare with residential uses. This is a creditable mitigation measure to minimise population exposing to the hazard of LPG Compound. As such, the increase to the overall risk level cause by the additional population in the Project is reduced to insignificant and the F-N curves of both cases overlap with each other.

Table 11 PLL of LPG Compound

Equipment	Base Case		Operation Case	
	PLL (no. of fatality per year)	% of total PLL	PLL (no. of fatality per year)	% of total PLL
LPG Vessel	8.38E-05	89.5%	8.38E-05	89.5%
LPG Road Tanker	7.73E-06	8.2%	7.73E-06	8.2%
Pipework, Vaporiser, Loading Arm	2.13E-06	2.3%	2.13E-06	2.3%
Total	**9.37E-05**	**100%**	**9.37E-05**	**100%**

Table 12 F-N Data

No. of fatality	Frequency (/year)	
	Case 1 – Base Case in 2036	Case 2 – Operation Case in 2036
1	7.78E-07	7.78E-07
2	6.54E-07	6.54E-07
3	5.84E-07	5.84E-07
4	5.54E-07	5.54E-07
5	5.21E-07	5.21E-07
6	4.96E-07	4.96E-07
8	4.64E-07	4.64E-07
10	4.44E-07	4.44E-07
12	4.24E-07	4.24E-07
15	4.14E-07	4.14E-07
20	3.88E-07	3.88E-07
25	3.83E-07	3.83E-07
30	3.80E-07	3.80E-07
40	3.76E-07	3.76E-07
50	3.71E-07	3.71E-07
60	3.67E-07	3.67E-07
80	3.60E-07	3.60E-07
90	2.65E-07	2.65E-07

No. of fatality	Frequency (/year)	
	Case 1 – Base Case in 2036	Case 2 – Operation Case in 2036
100	2.64E-07	2.64E-07
120	2.36E-07	2.36E-07
150	2.24E-07	2.24E-07
200	2.22E-07	2.22E-07
250	1.85E-07	1.85E-07
300	1.85E-07	1.85E-07
400	4.35E-08	4.35E-08
500	1.05E-08	1.05E-08
600	1.91E-09	1.91E-09
700	4.16E-12	4.16E-12

Note: Values less than 1E-9 per year are not shown in the figure of F-N curve

8.0 Mitigation Measure

The societal risk of the LPG Compound lies within the ALARP region. The Site is about 125m away from the LPG Compound. As shown from the FN-curves in **Figure 6** and PLL presented is **Table 11**, the implementation of the Project contributes insignificantly to the overall societal risk level of the LPG Compound. Hence, mitigation measure to further reduce the overall societal risk level of the LPG Compound is not necessary for the Project.

9.0 Conclusion

URA has proposed Ma Tau Wai Road/ Lok Shan Road Development Project (KC-020, hereinafter refer as "the Project") at To Kwa Wan, Kowloon City. This QRA has studied the risk impact of the LPG Compound at Lok Man Sun Chuen to the Project and the surrounding population in future years when the Project is completed for population intake.

The results of the study have shown that the individual risks of the LPG Compound are in compliance with the HKRG. The individual risk level at the Project is less than 1×10^{-9} per year for risk posed by the LPG Compound near LMSC Block G in the west.

The societal risks of LPG Compound near LMSC Block G, for both cases with/without implementation of the Project, lies in ALARP of the HKRG. The societal risks results, in form of FN curves, for both case are overlapping. The contribution of the Project to the societal risk level is insignificant. In consideration of the separation distance of approximately 125m between the Site and LPG Compound and also the allocation of facilities with relatively low population density on lower floors of the development, no mitigation measure is required in the Site.

10.0 References

[1] *The Hong Kong Planning Standards and Guidelines*, Planning Department, Hong Kong, 2024

[2] Approved QRA Report – *Quantitative Risk Assessment for Kau Pui Lung Road / Chi Kiang Street Development Scheme (CBS-2:KC)*, Urban Renewal Authority, 2020

[3] *Quantitative Risk Assessment Methodology for LPG Installations*, Dr. Alan B. Reeves, Francis C. Minah, Vincent H.K. Chow, Conference on Risk & Safety Management in the Gas Industry, EMSD & HKIE, Hong Kong, 1996

[4] *LPG Installation Design and General Risk Assessment Methodology Employed by the Gas Standards Office*, K. Wittle, 1993

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[7] Projections of Population Distribution 2023 – 2031, Planning Department, Hong Kong

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[10] Guidelines for Quantitative Risk Assessment *"Purple Book", CPR18E, Committee for the Prevention of Disasters, 2005.*

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[12] *Risk of Hazardous Materials Release Following an Earthquake*, Kathleen J. Tierney, Preliminary Paper #152, University of Delaware, Disaster Research Centre, 1990

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[14] *Air Traffic Statistics: https://www.cad.gov.hk/english/statistics.html,* The Civil Aviation Department, last accessed on 01/09/2025

[15] *Loss Prevention in the Process Industries*, Butterworth-Heinemann, United Kingdom, F. Lees, 2005.

Figures

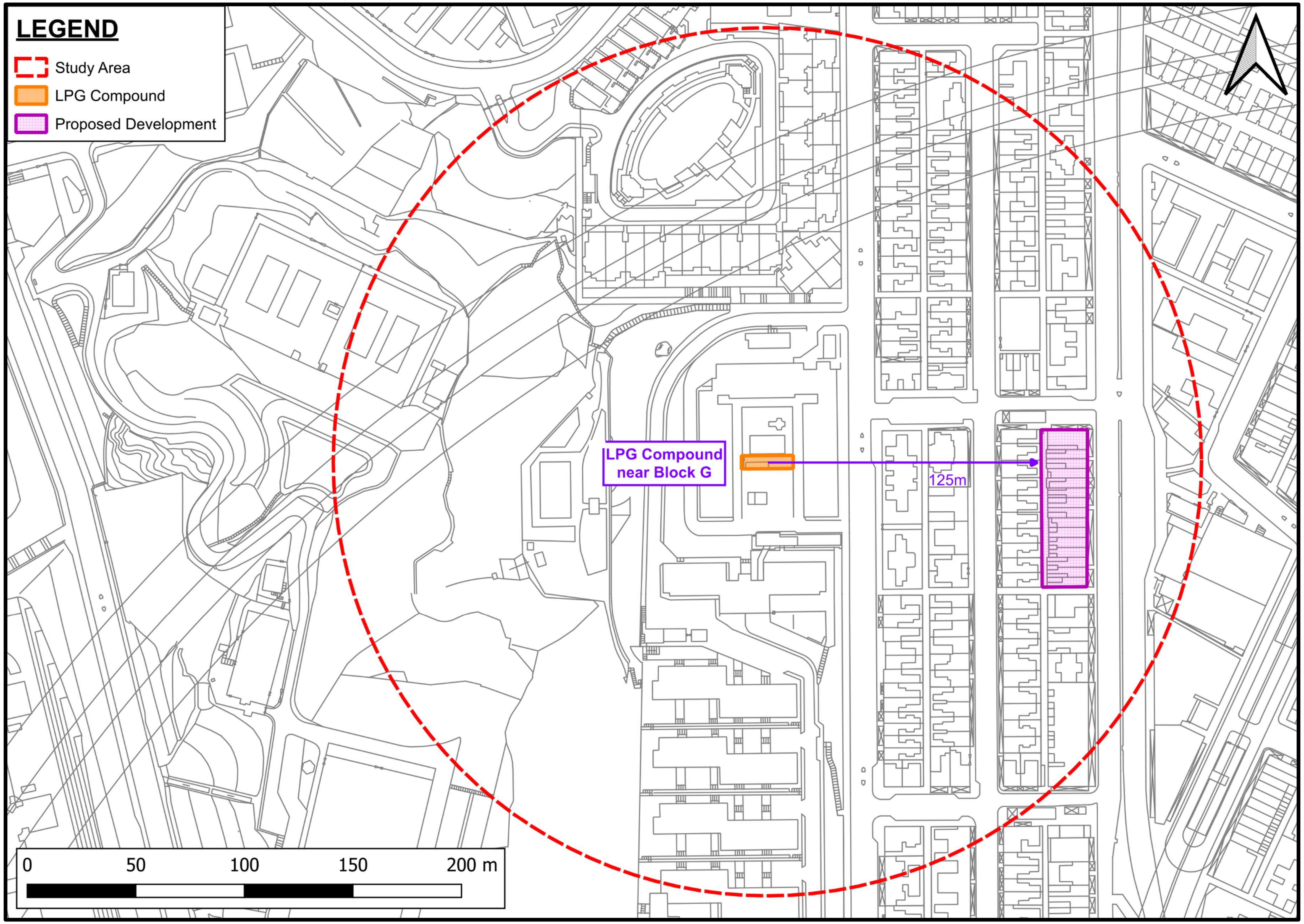


Figure 1 **Location of the Project Site and Study Area**

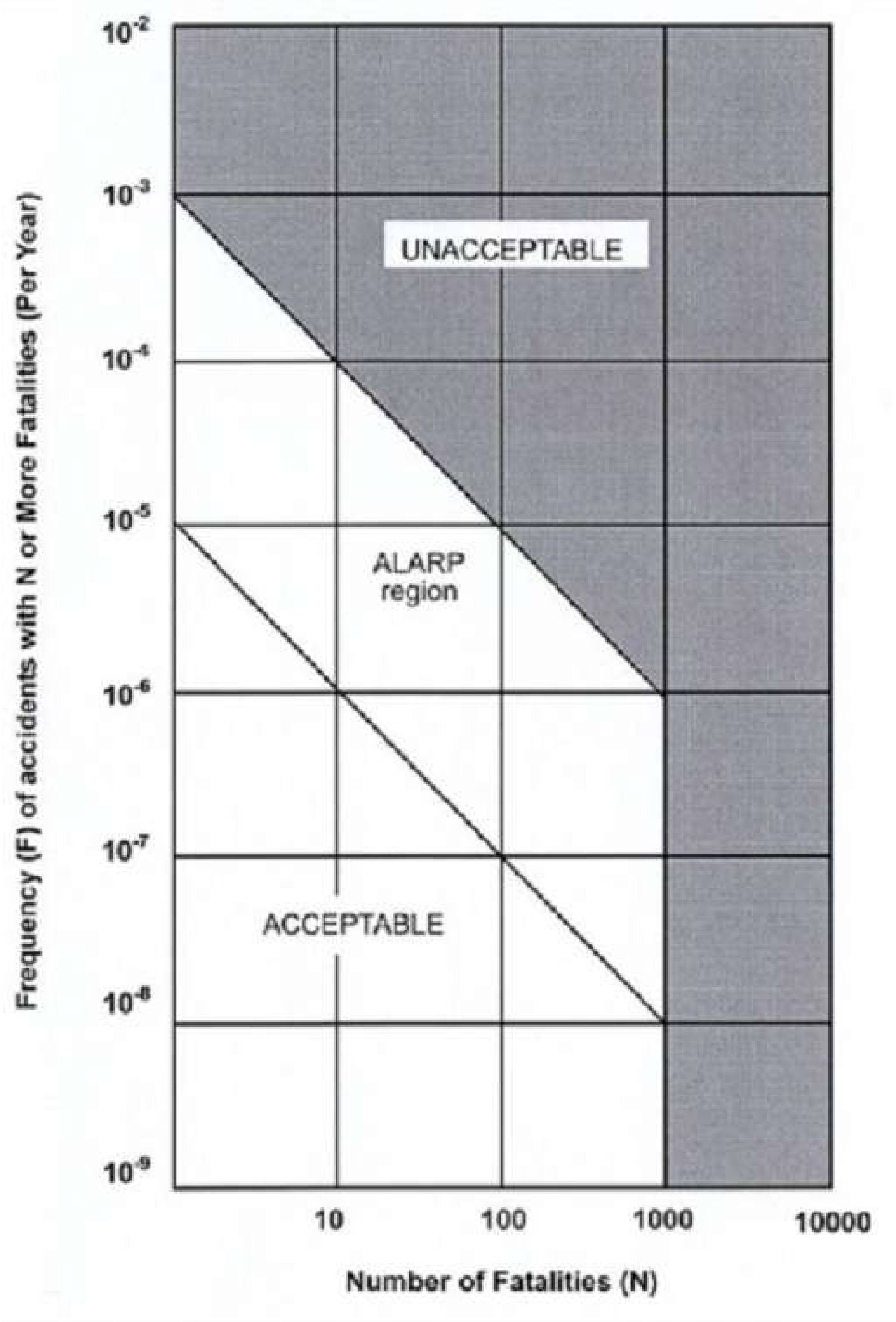


Figure 2 **Societal Risk Guidelines from Hong Kong Planning Standards and Guidelines**

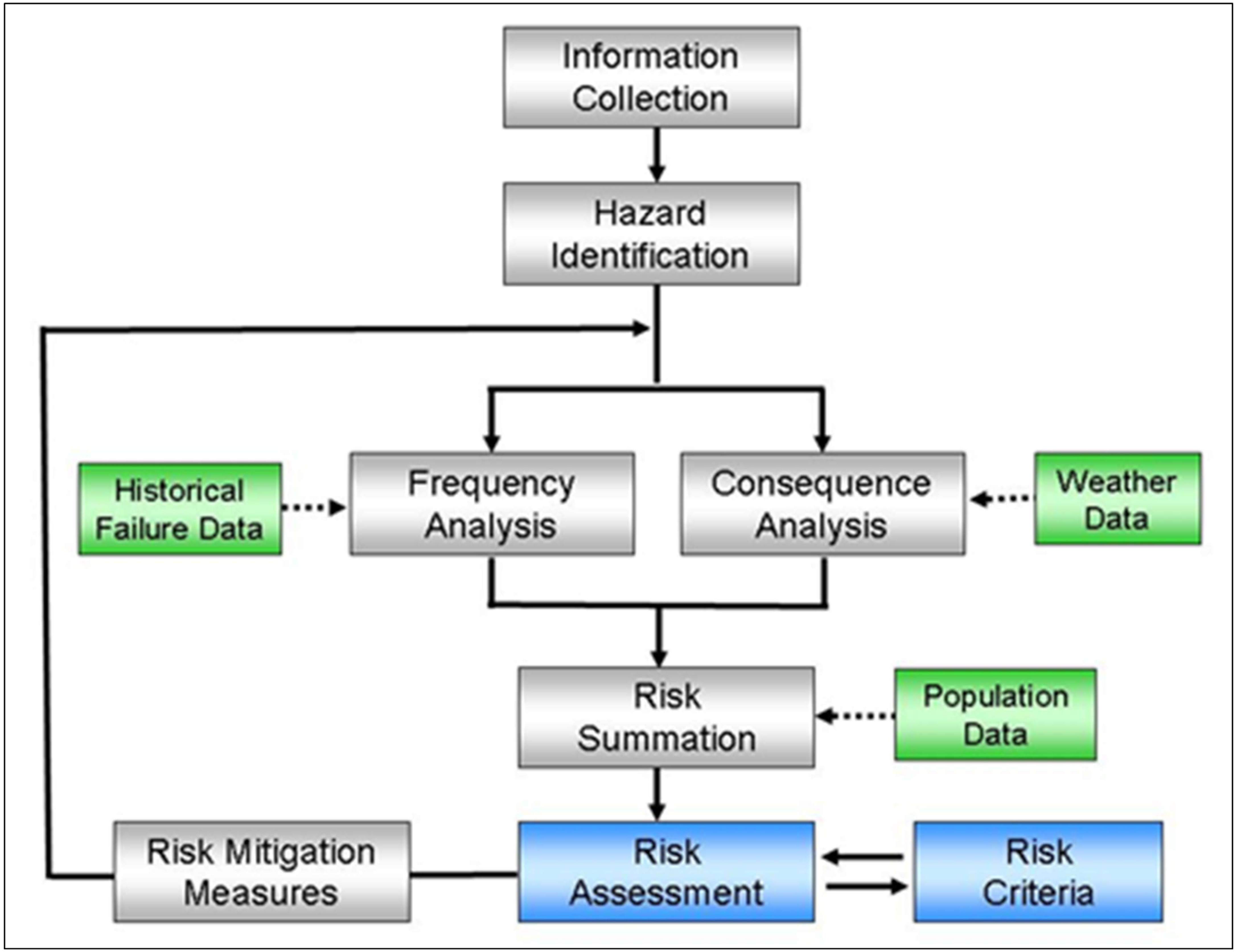

Information Collection
Hazard Identification
Historical Failure Data
Frequency Analysis
Consequence Analysis
Weather Data
Risk Summation
Population Data
Risk Mitigation Measures
Risk Assessment
Risk Criteria

Figure 3 Quantitative Risk Assessment Methodology

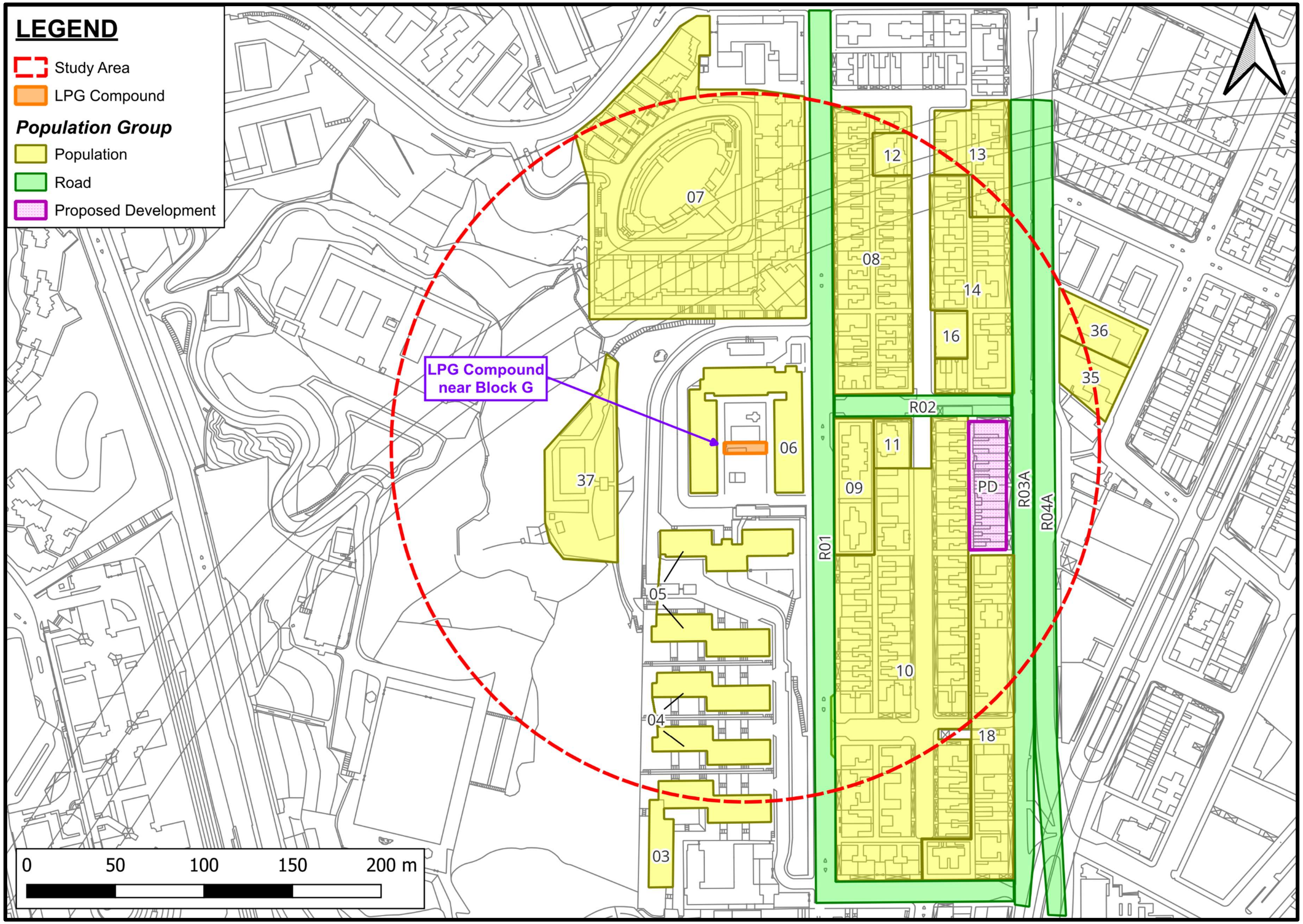


Figure 4 **Population Considered in This Study**

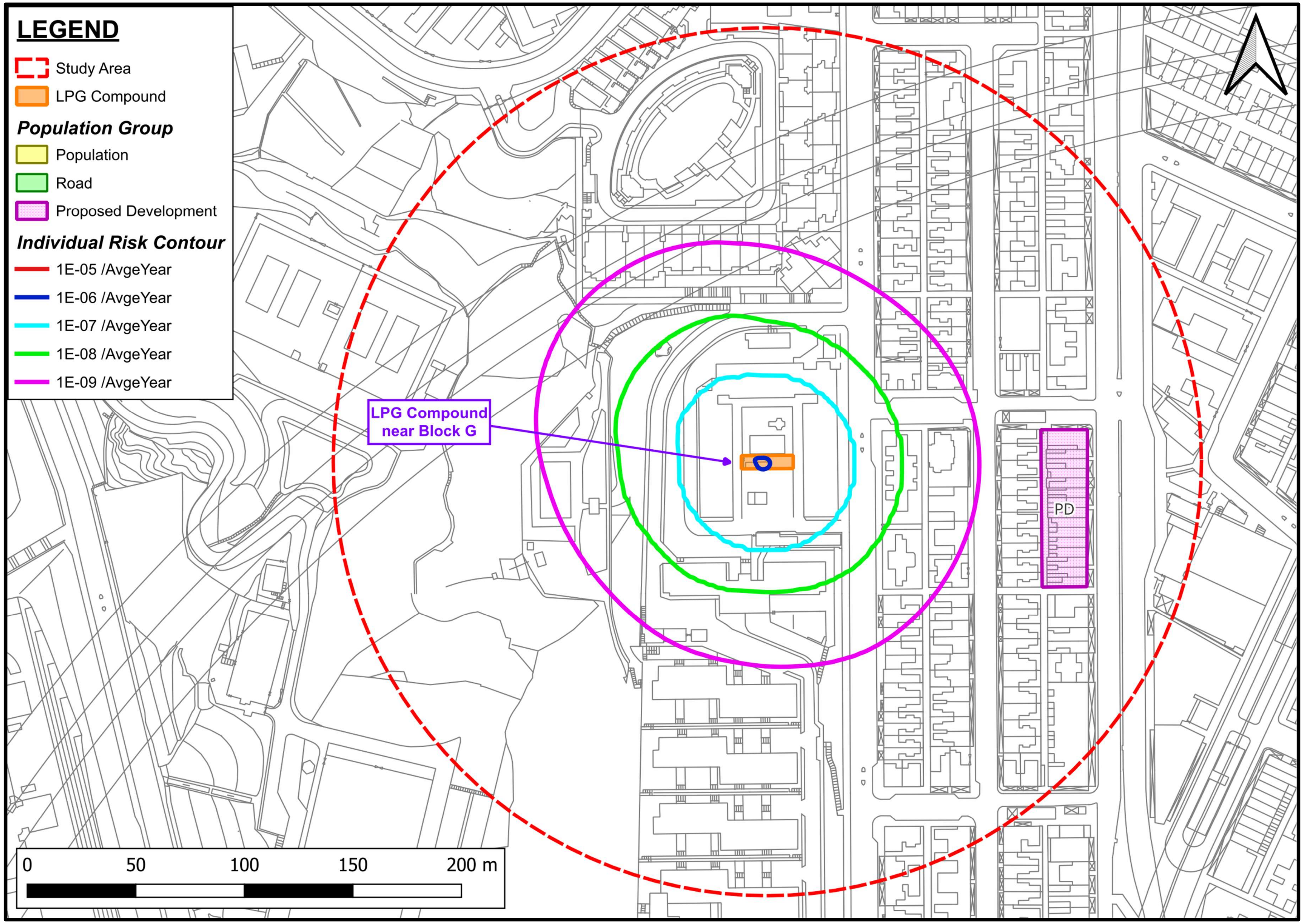


Figure 5 **Individual Risk Contours of the LPG Compound**

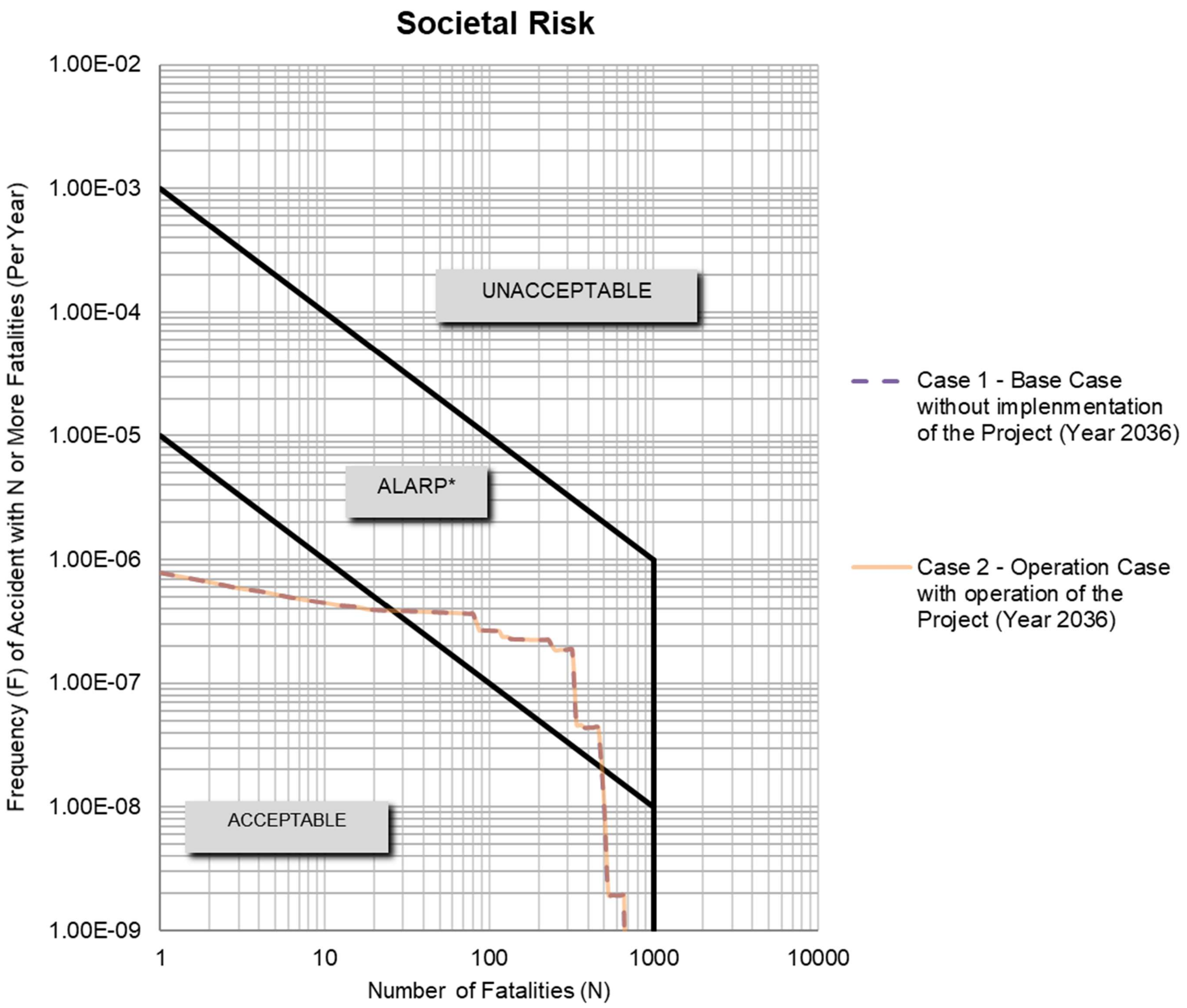


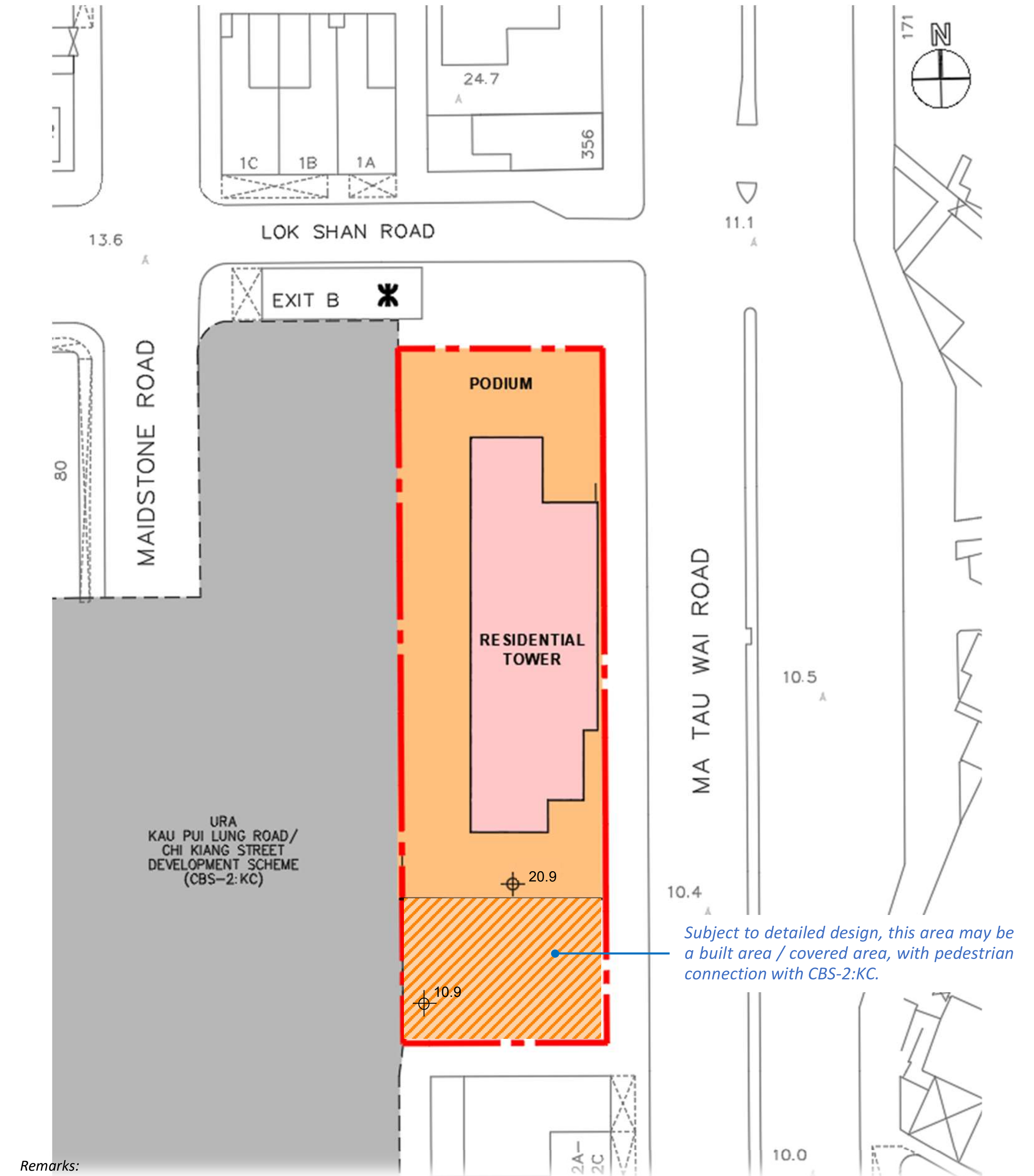
Figure 6 Societal Risk Results

Annex A:
Details of LPG Installations

A1. Information of LPG Compound at Block G

Description	Value	Units
Vessel		
Number of Vessels	1	
Full load capacity of Vessel	3.50	te
Radiography Vessel	100	%
Stress Relief Vessel	100	%
Mounded or Below Ground? (M/B)	M	
Safety Devices	Relief valve	
Road Tanker		
Average size of road tankers	19	kL
Delivery Frequency	220	per year
Road Tanker Resident Time	25	min
Pumping rate	160	L/min
Safety Devices	Manual Isolation, ESD, EFV /Relief valve	
Filling Line to Vessel		
Line Length (from loading arm to vessel)	17	m
Line Diameter	50	mm
Safety Devices	NRV, Double check valve, Relief valve, Pull away coupling, Manual Isolation	
Supply Line to Vaporiser		
Line Length	8	m
Line Diameter	40	mm
Safety Devices	Manual Isolation, ESD, EFV	
Vaporiser		
Number of Vaporisers	3	
Size of Vaporiser	200	Kg/h
Coil Length	5	m
Coil Diameter	25	mm
Loading Arm		
Loading Arm Length	2	m
Loading Arm Diameter	32	mm

Annex B:
Layout Plan of the Project



Remarks:
This S16 Planning Application is a "non-scheme-based" submission. This notional design layout is solely for illustration purpose and for conducting necessary technical assessments. Except for any planning condition(s) to be imposed, the design of the future development will not be bounded by the notional design submitted in the S16 Planning Application.

URA undertakes that the portion of the future combined development within the Application Site would not exceed maximum DPR of 8.0 and total PR of 9.0.

Application Site Boundary

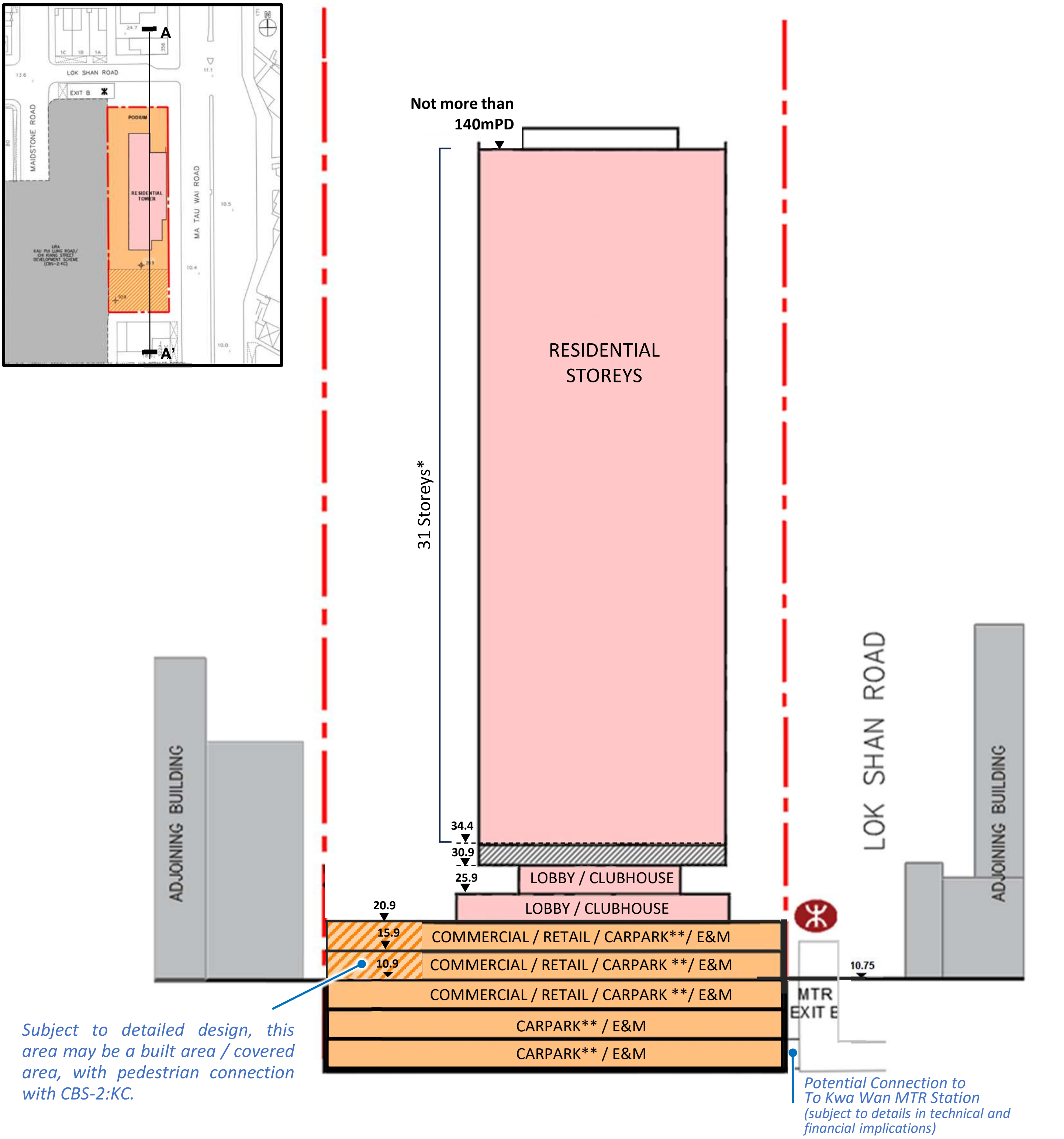
NOTIONAL BLOCK PLAN

MA TAU WAI ROAD / LOK SHAN ROAD DEVELOPMENT PROJECT (KC-020)

市區重建局 URBAN RENEWAL AUTHORITY

Figure 3.1

Key Plan



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URA undertakes that the portion of the future combined development within the Application Site would not exceed maximum DPR of 8.0 and total PR of 9.0.

** Reference to typical floor-to-floor height of 3.3m to 3.5m adopted in Hong Kong's private residential development.*

*** The proposed location of the carpark may reference to the latest PNAP APP-2, which permits full GFA exemption for up to two levels of above-ground carparks. Details will be worked out at detailed design stage.*

Application Site Boundary	NOTIONAL SECTION PLAN MA TAU WAI ROAD / LOK SHAN ROAD DEVELOPMENT PROJECT (KC-020)	市區重建局 URBAN RENEWAL AUTHORITY Figure 3.2

Annex C: Calculation of Transient Population

C1. Estimation of Average Occupancy per Vehicle

The average occupancies of vehicles on roads concerned are estimated from statistics of nearby traffic stations in Annual Traffic Census 2023.

Station No.	4212		4212 (no DD Fr. Bus)	
Vehicle Type	Pro	Ocp	Pro	Ocp
Motor Cycle	6.2	1.1	6.2	1.1
Private Car	36.8	1.4	36.8	1.4
Taxi	22.6	1.8	22.6	1.8
Private Light Bus	1.2	4.4	1.2	4.4
Public Light Bus	2.8	9.5	2.8	9.5
Light Goods Vehicle	16.1	1.5	16.1	1.5
M&H Goods Vehicle	2.8	1.3	2.8	1.3
Non Fr. Bus	1.9	9.9	1.9	9.9
SD Fr. Bus	0.1	2.0	0.1	2.0
DD Fr. Bus	9.6	29.9		
Average Occupancy	4.65		1.78	

Note:
(1) *Average occupancy* $= \sum(Probability_i \times Occupancy_i)/\sum Probability_i$

C2. Forecasted Traffic Flow from Traffic Forecast of the Project

The traffic forecast of the Project is adopted as follows:

ID	Road	Index No.	Morning Peak Hour Traffic (veh/hr)	Evening Peak Hour Traffic (veh/hr)
R01	Kau Pui Lung Road	26&27	850	700
R02	Lok Shan Road	31	350	350
R03A	Ma Tau Wai Road (NB)	91	1100	1200
R04A	Ma Tau Wai Road (SB)	92	1800	1450

C3. Traffic Variation within the Day

The traffic flow variation on all roads within study area is assumed to be same as that at Traffic Station no. 4212 Chatham Road and Ma Tau Wai Road (from San Lau Street to Chi Kiang Street).

Station No.	Road	Ratio of Day-time and Night-time Traffic Flow		Ratio to WDD Traffic Flow	
		Day	Night	Day	Night
4212	Chatham Road and Ma Tau Wai Road (from San Lau Street to Chi Kiang Street)	62%	38%	100%	61%

C4. Calculation of Transient Population

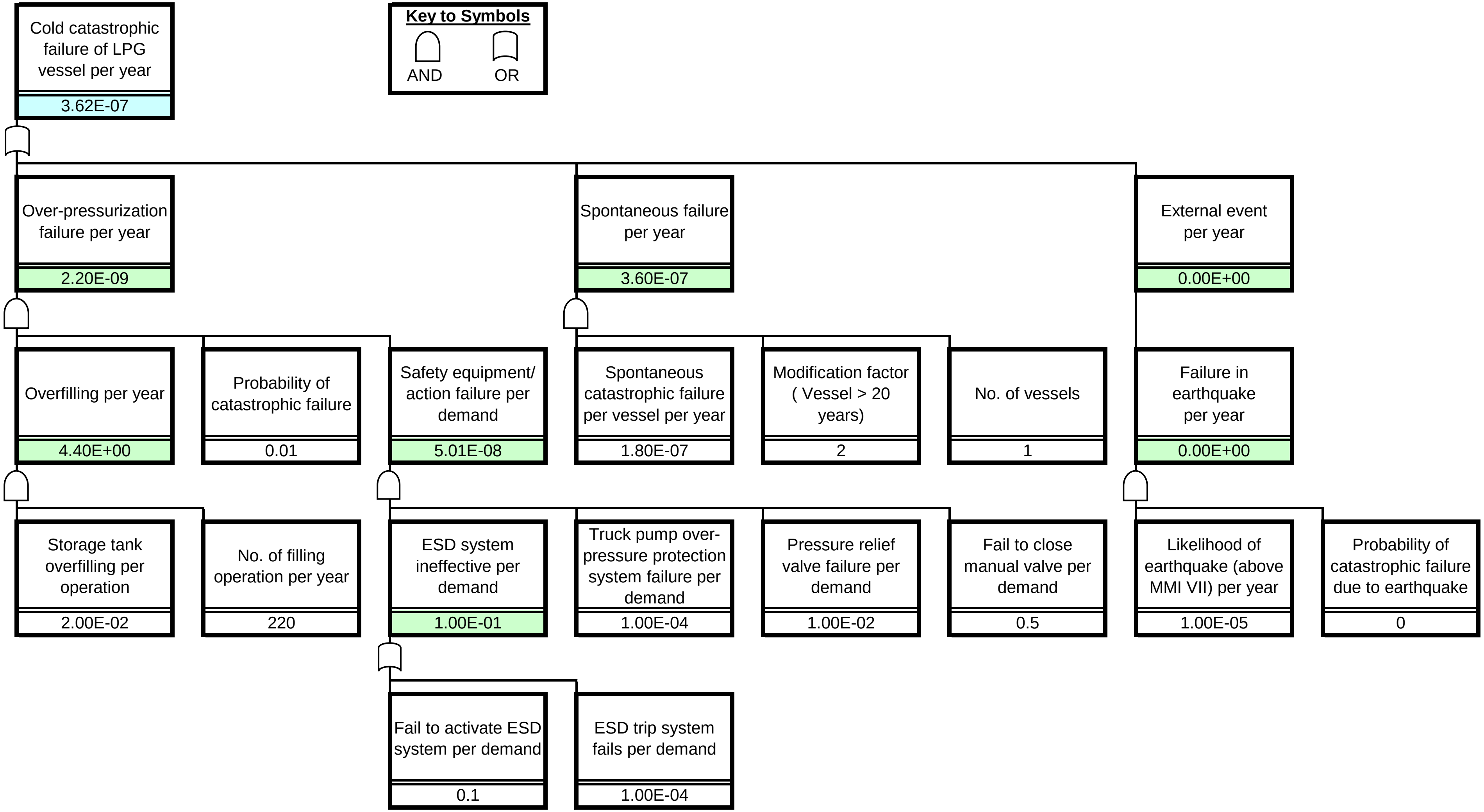
ID	Road Name	Average Occupancy	Speed (km/hr)	Road Length (m)	Daytime Traffic Population	Pedestrian	Daytime Population
R01	Kau Pui Lung Road	1.78	50	600	19	80	99
R02	Lok Shan Road	1.78	50	100	2	20	22
R03A	Ma Tau Wai Rd (NB)	4.65	50	450	22	40	62
R04A	Ma Tau Wai Rd (SB)	4.65	50	460	69	30	99

Note:

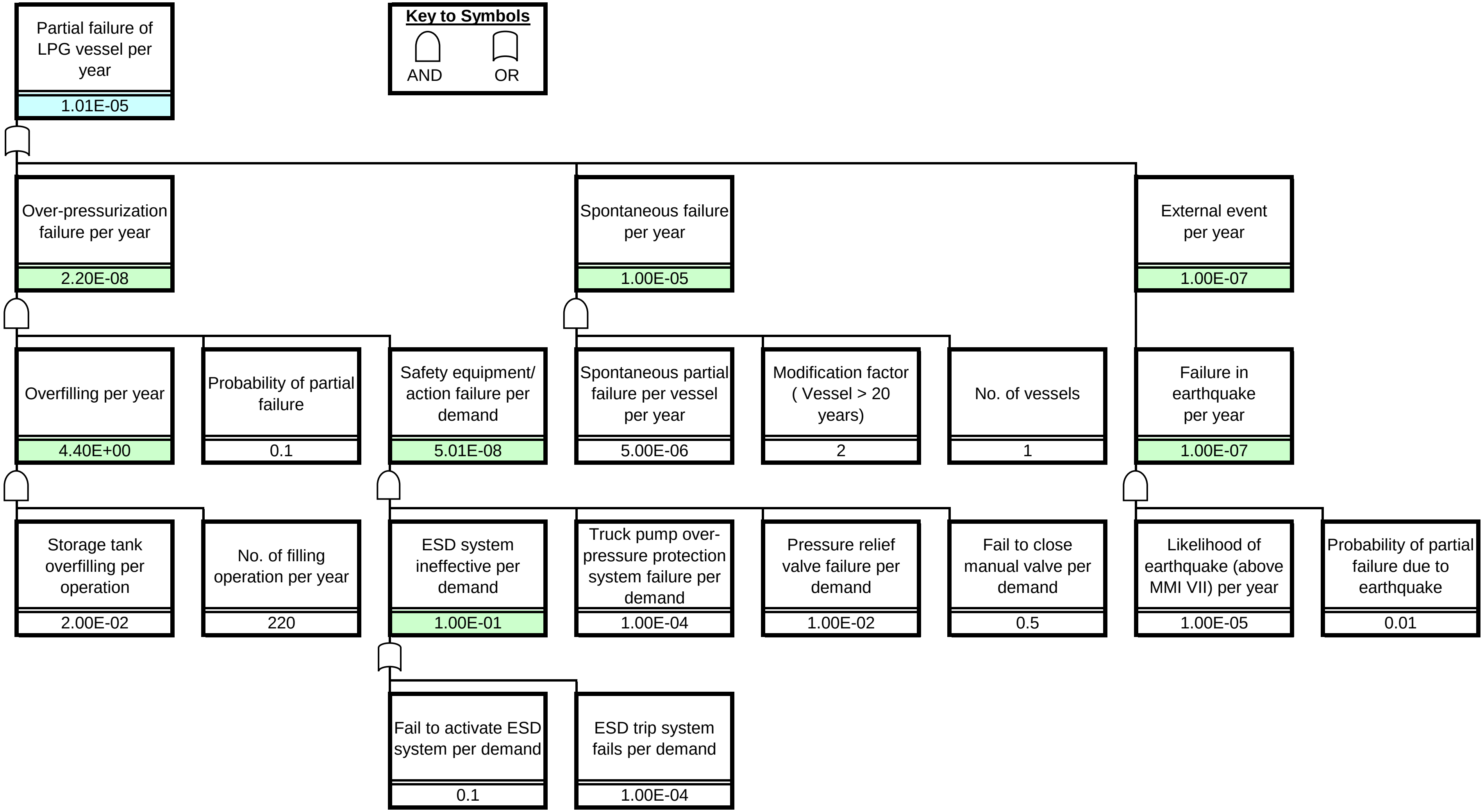
(1) Daytime Traffic Population = Morning Peak Hour Traffic × Average Occupancy × Road Length / Speed

Annex D:
Fault Tree Analysis

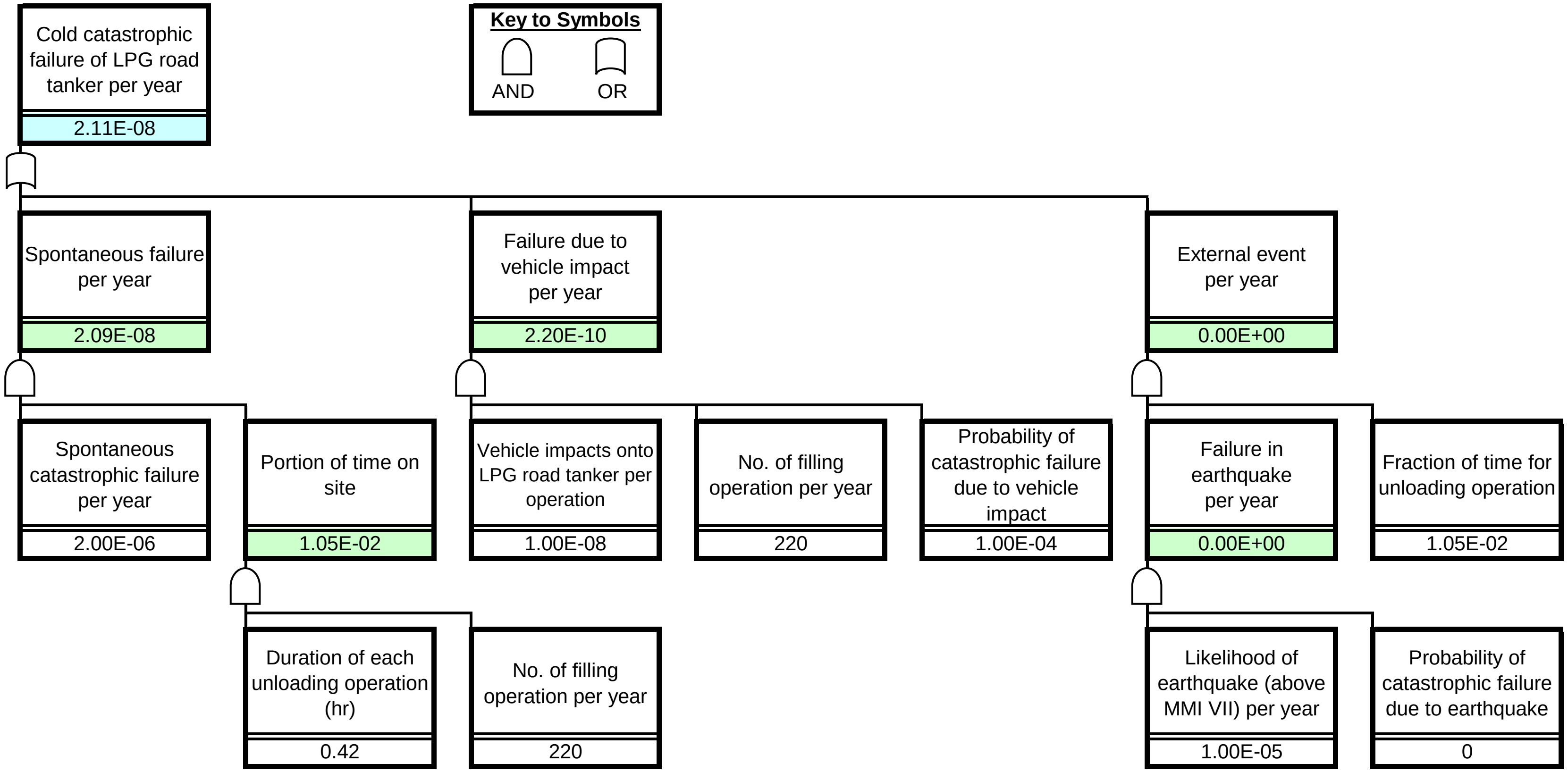
Fault Tree 1 - Cold Catastrophic Failure of LPG Vessel



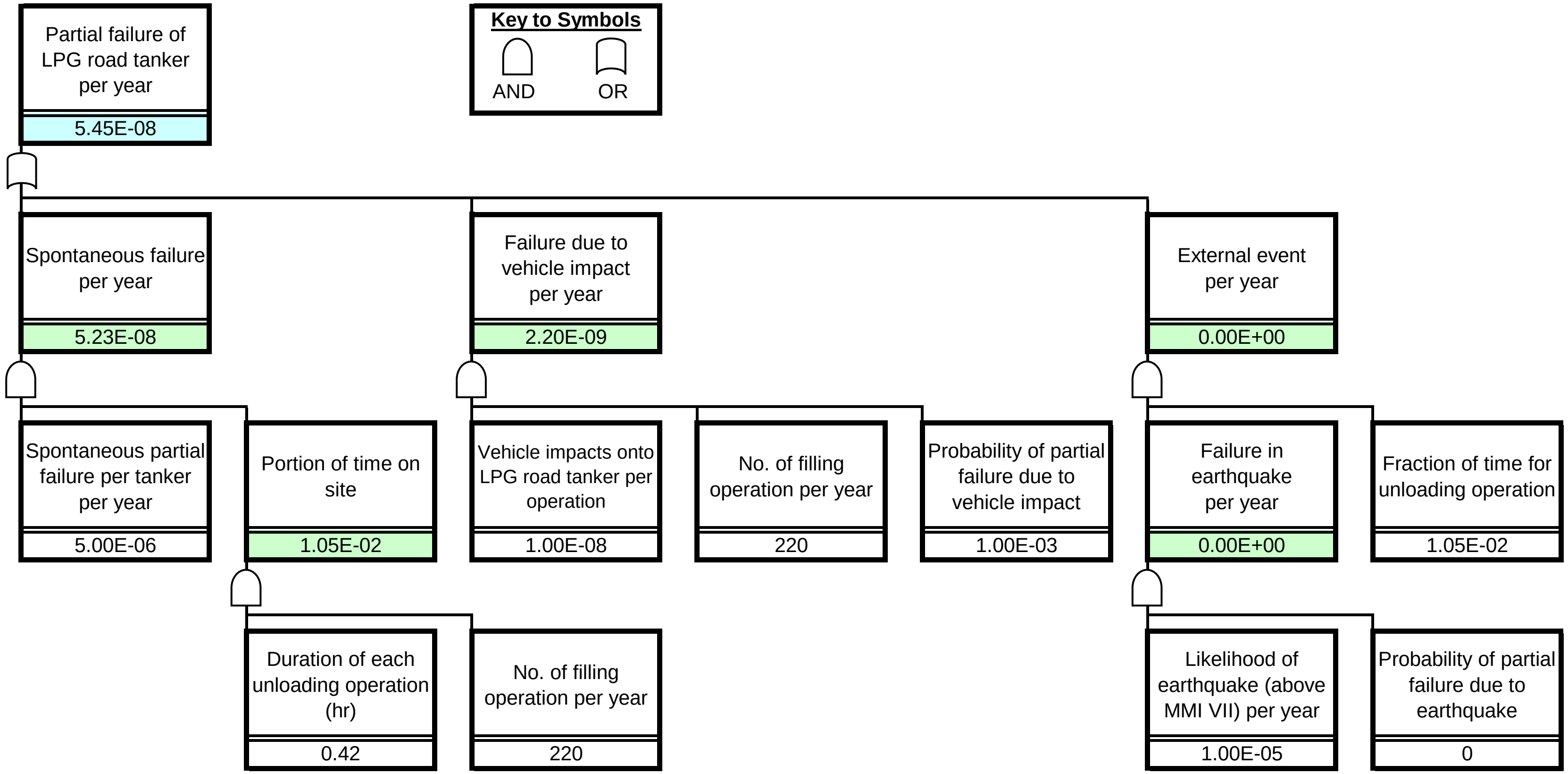
Fault Tree 2 - Cold Partial Failure of LPG Vessel



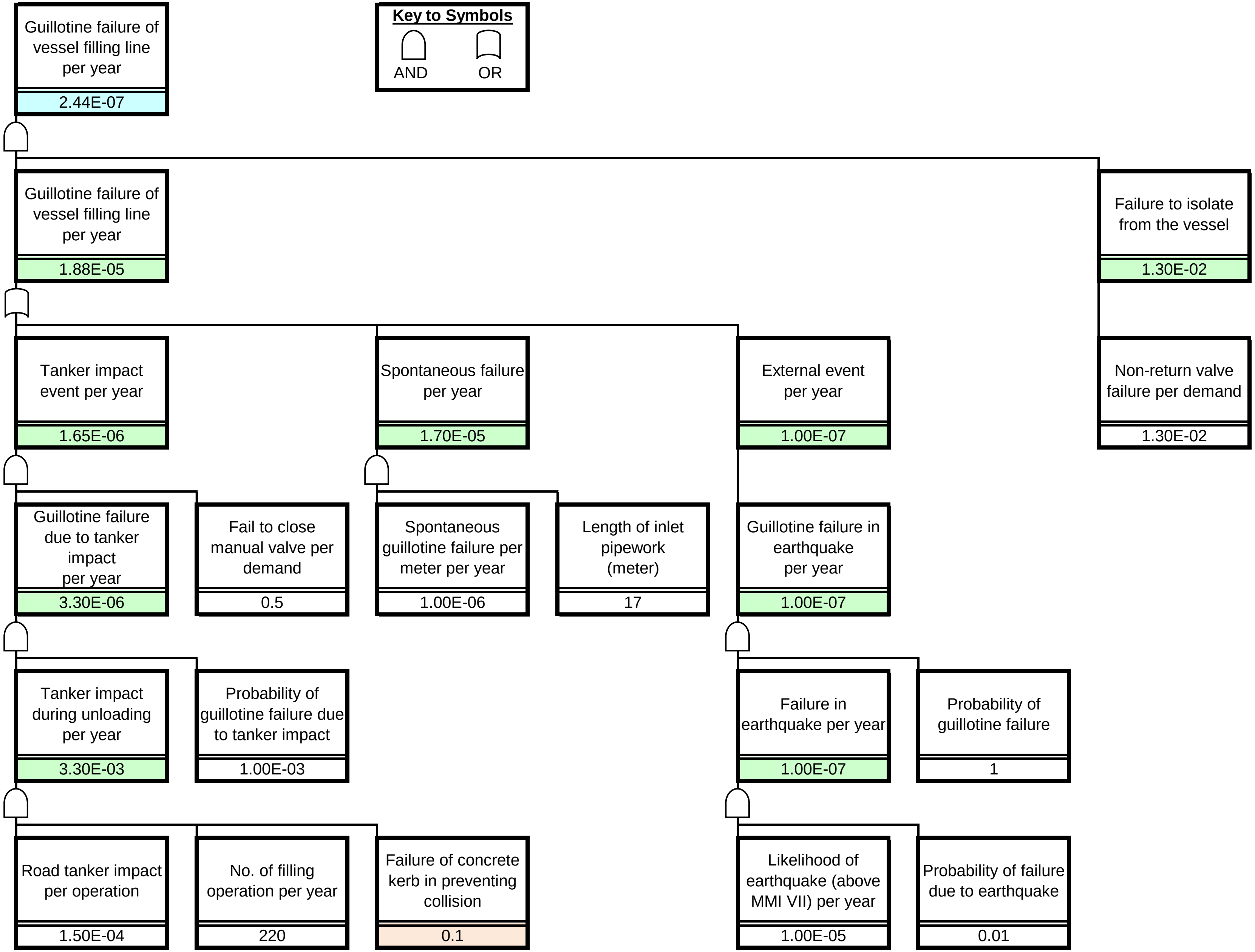
Fault Tree 3 - Cold Catastrophic Failure of Road Tanker



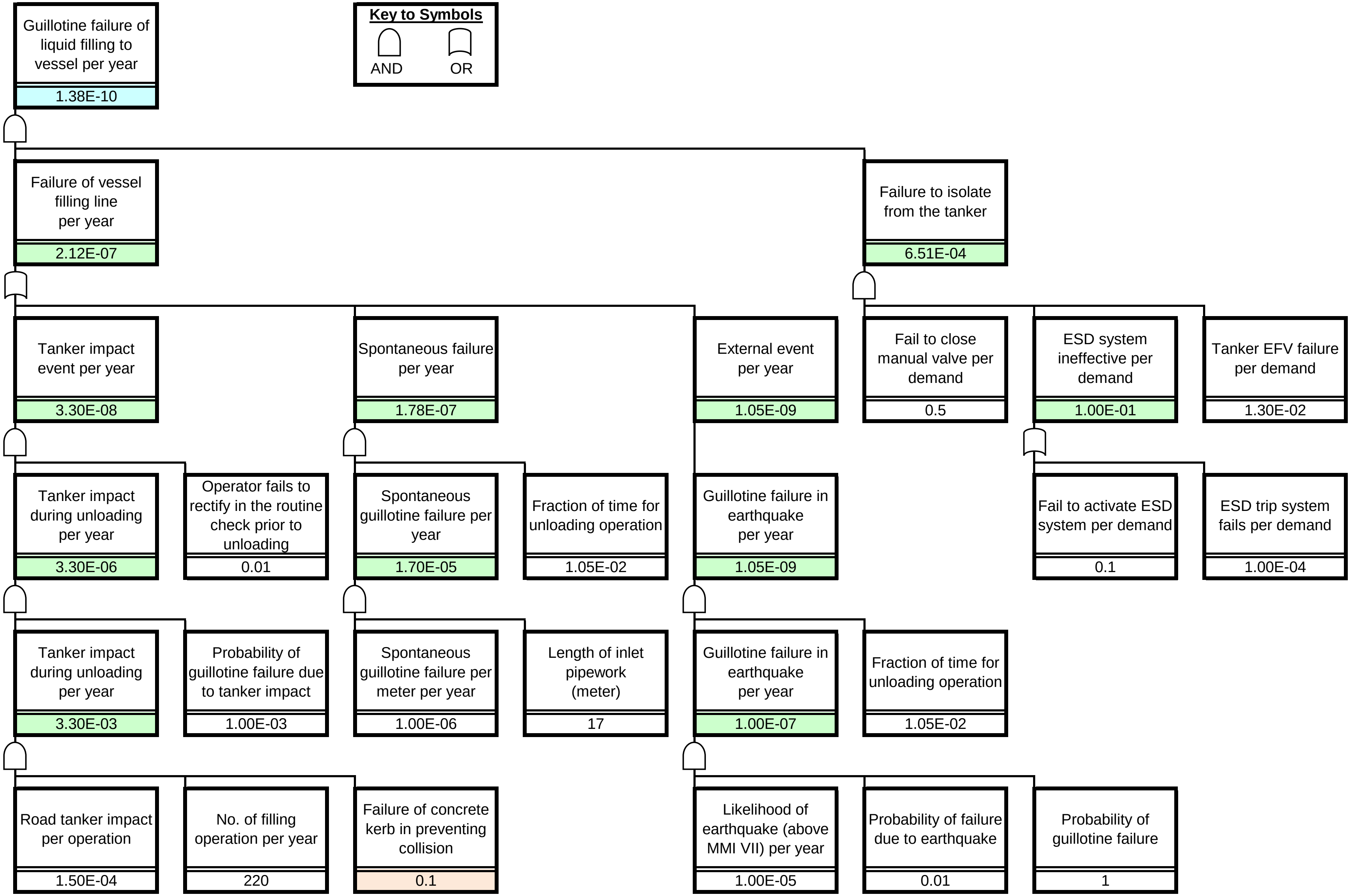
Fault Tree 4 - Cold Partial Failure of LPG Road Tanker



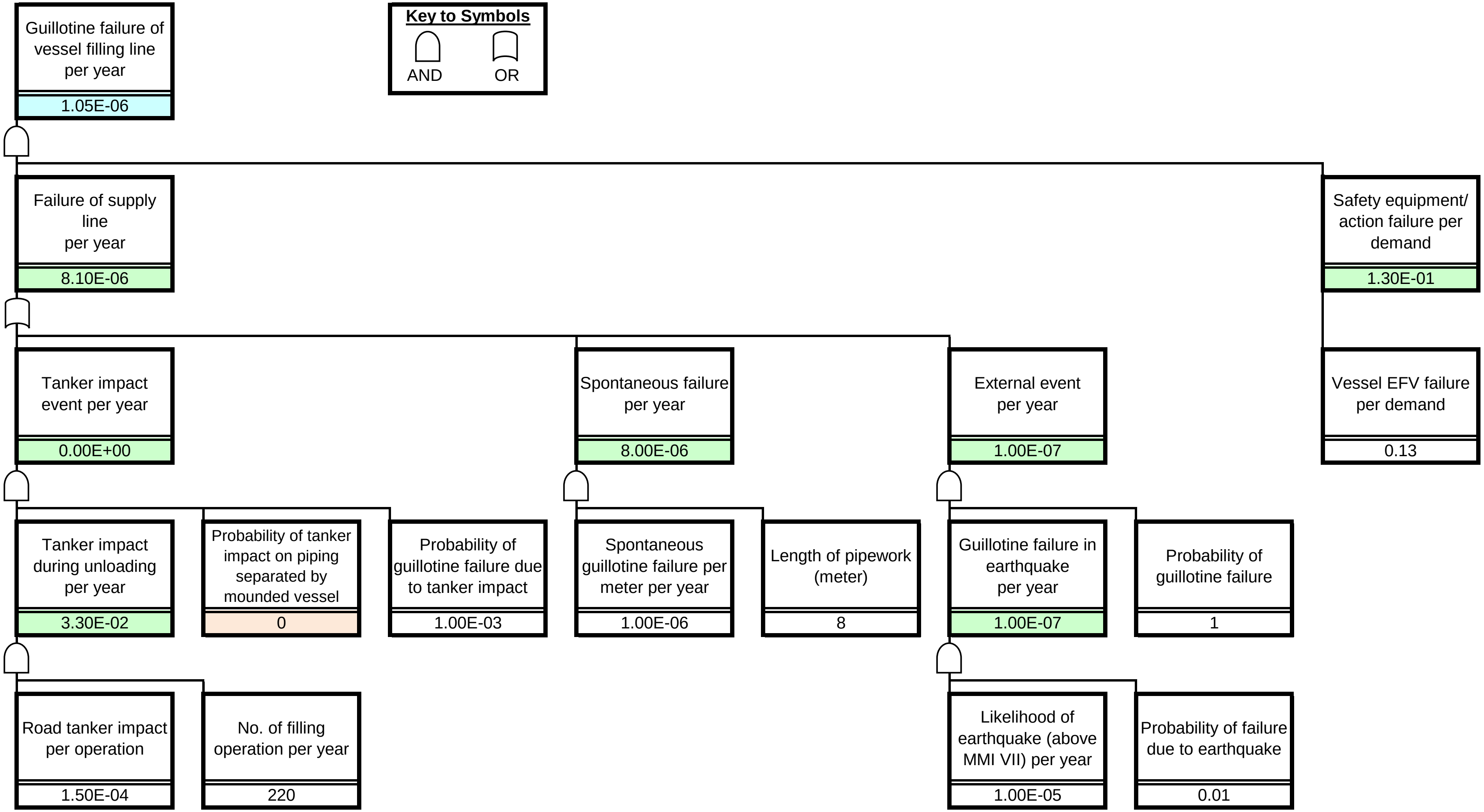
Fault Tree 5a - Guillotine Failure of Vessel Filling Line (Release from Vessel)



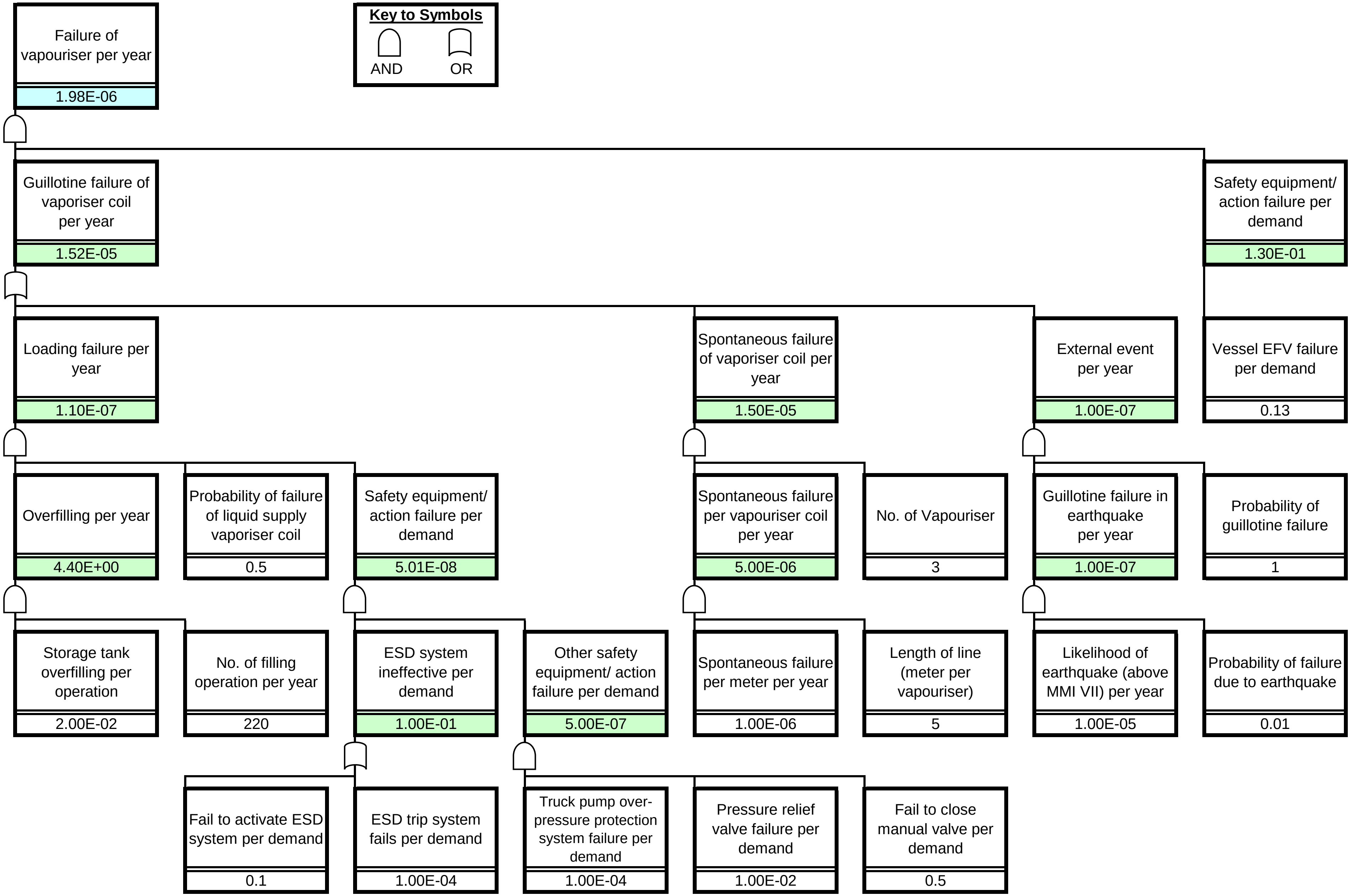
Fault Tree 5b - Guillotine Failure of Vessel Filling Line (Release from Tanker)



Fault Tree 6 - Guillotine Failure of Supply Line to Vapouriser

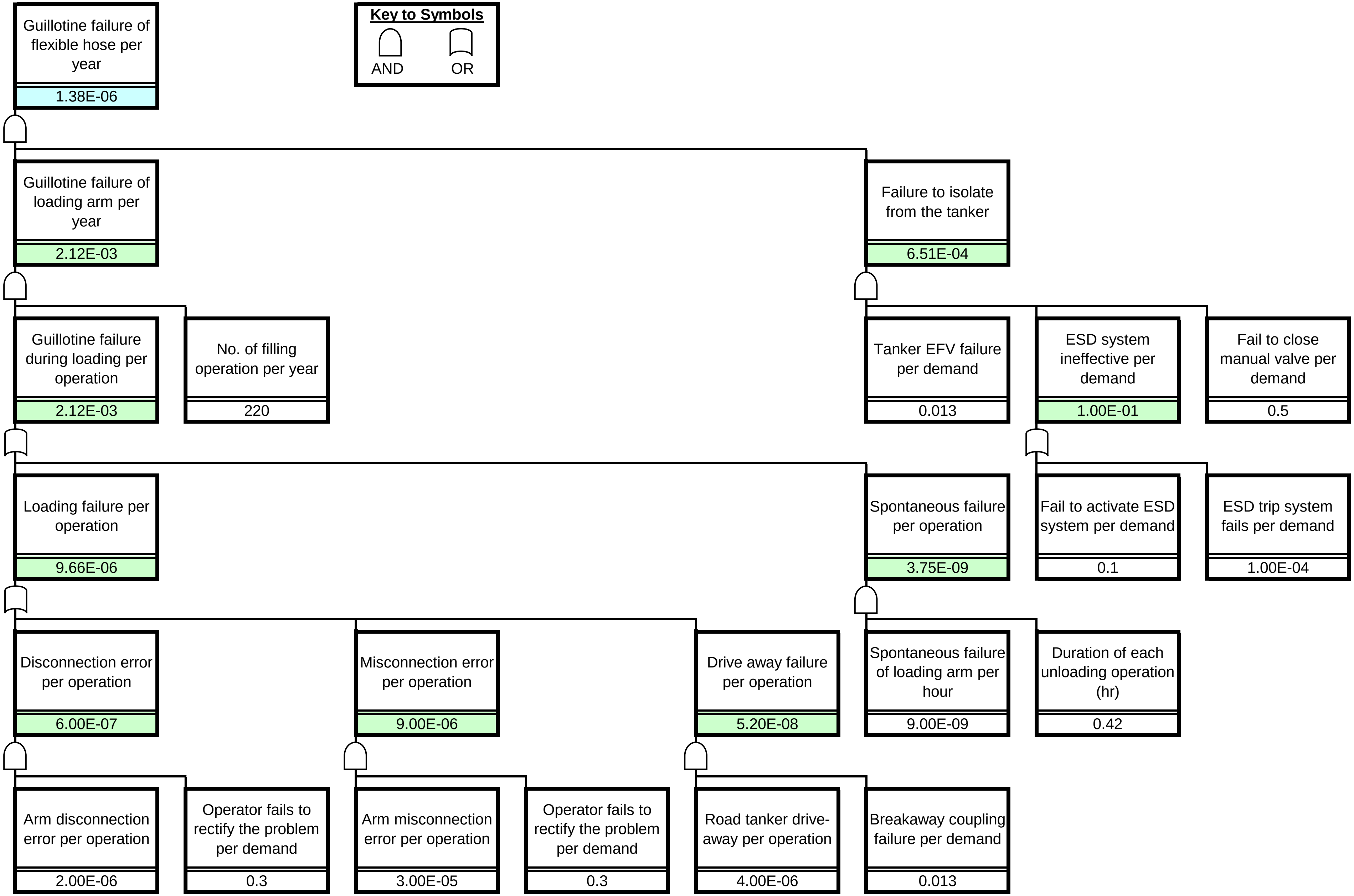


Fault Tree 7 - Failure of Vaporiser



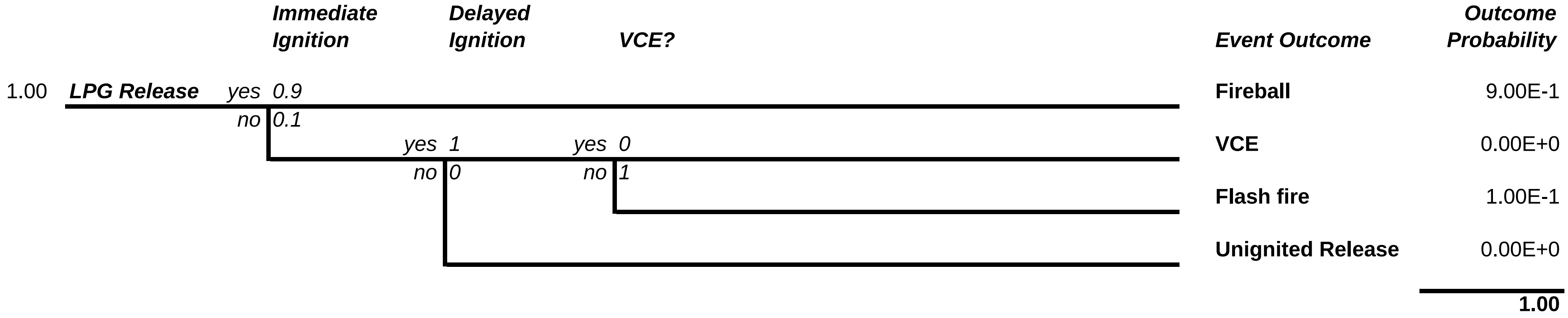
Fault Tree 8a - Guillotine Failure of Loading Arm (Release from Vessel)

Fault Tree 8b - Guillotine Failure of Flexible Hose (Release from Tanker)

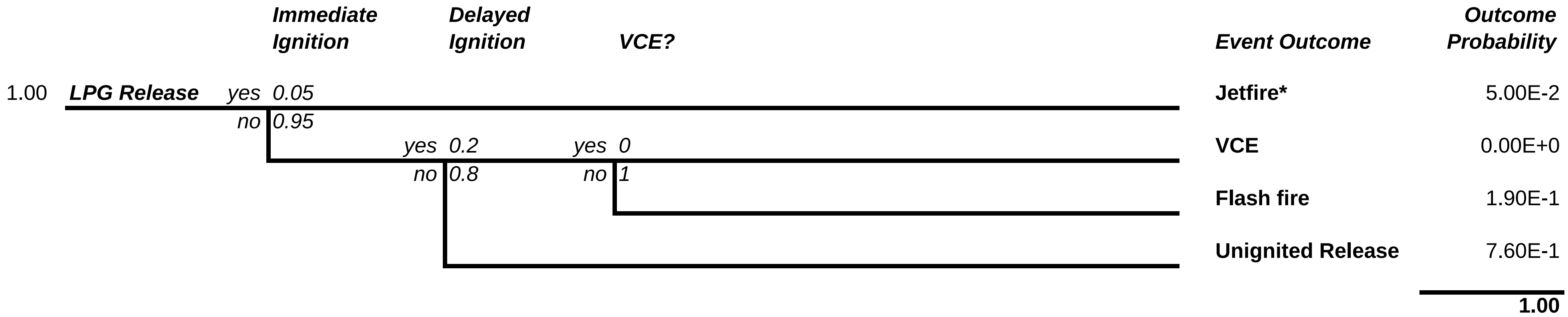


Annex E:
Event Tree Analysis

ETA 1 - LPG Instantaneous Release from Vessel / Road Tanker

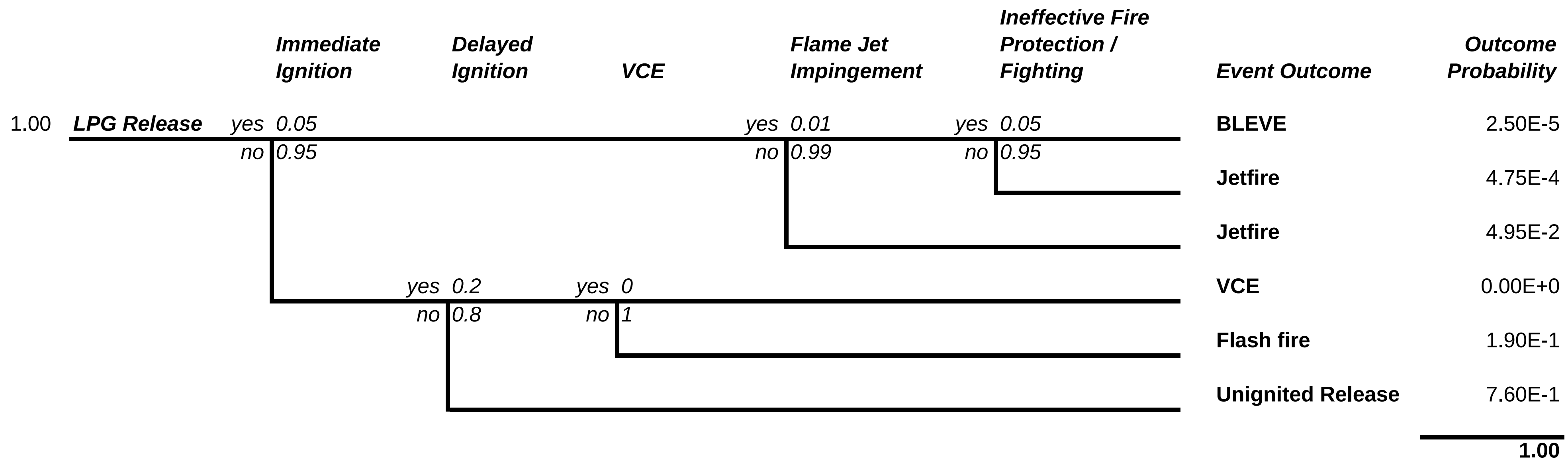


ETA 2 - LPG Continuous Release from Vessel / Road Tanker

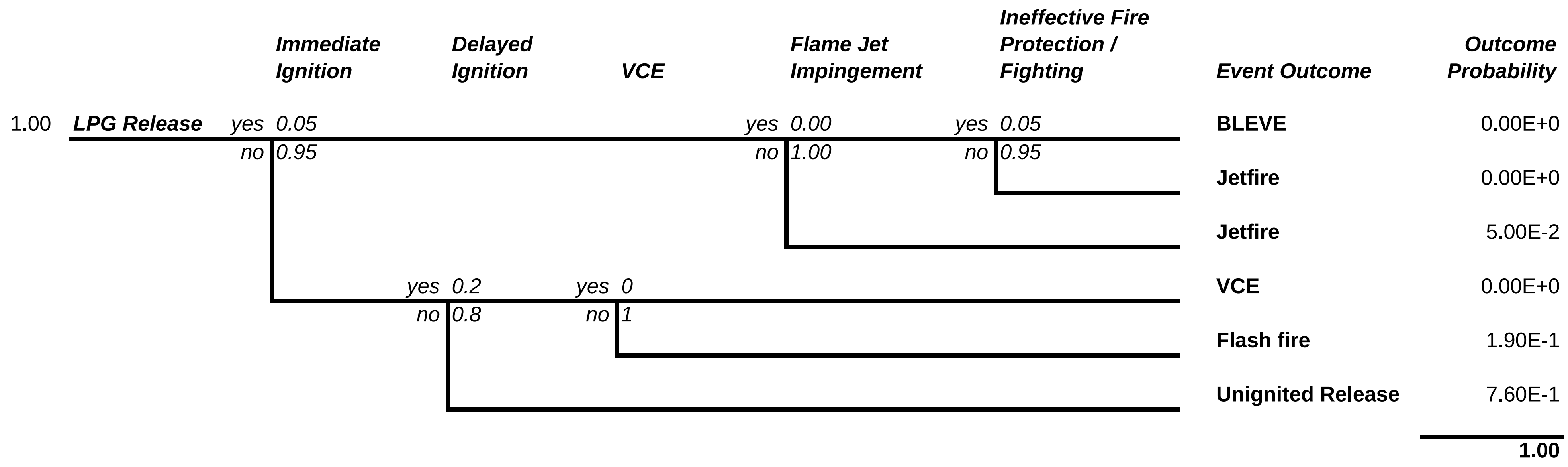


*** Jetfire from underground installations is considered in vertical direction**

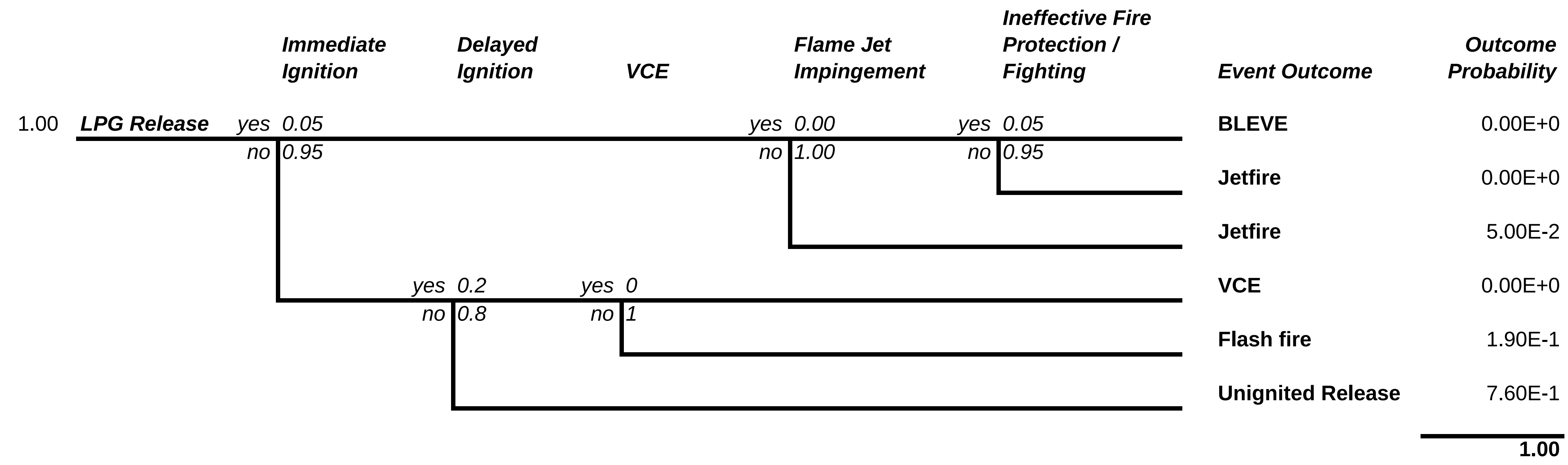
ETA 3 - LPG Continuous Release from Outdoor Pipework



ETA 4 - LPG Continuous Release from Outdoor Pipework (BLEVE Prevented)



ETA 5 - LPG Continuous Release from Indoor Pipework (BLEVE Prevented)



Annex F: Atmospheric Stability Class-Wind Speed Frequencies

Day Time Atmospheric Stability Class-Wind Speed Frequencies at Kai Tak Weather Station (Year 2024)

Wind Speed	STABILITY CLASS						Total
	A	B	C	D	E	F	
0-2	6.4%	4.7%	0.0%	5.6%	0.0%	7.5%	24.2%
2-4	4.5%	20.2%	9.2%	12.7%	5.8%	0.8%	53.1%
4-6	0.0%	7.9%	5.6%	6.7%	0.3%	0.0%	20.5%
6-8	0.0%	0.0%	0.6%	1.4%	0.0%	0.0%	2.0%
>8	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.2%
Total	10.9%	32.7%	15.5%	26.5%	6.1%	8.3%	100.0%

Night Time Atmospheric Stability Class-Wind Speed Frequencies at Kai Tak Weather Station (Year 2024)

Wind Speed	STABILITY CLASS						Total
	A	B	C	D	E	F	
0-2	0.0%	0.0%	0.0%	1.0%	0.0%	40.9%	41.9%
2-4	0.0%	0.0%	0.0%	14.9%	25.2%	5.1%	45.2%
4-6	0.0%	0.0%	0.0%	10.6%	0.5%	0.0%	11.2%
6-8	0.0%	0.0%	0.0%	1.5%	0.0%	0.0%	1.5%
>8	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.2%
Total	0.0%	0.0%	0.0%	28.2%	25.8%	46.0%	100.0%