Appendix 9

Quantitative Risk Assessment

Prepared for

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PROPOSED COMPOSITE REDEVELOPMENT WITH TRADE MART/EXHIBITION AND COMMERCIAL, RESIDENTIAL, SOCIAL WELFARE FACILITIES AND SCHOOL USES AND MINOR RELAXATION OF BUILDING HEIGHT RESTRICTION, NEW KOWLOON INLAND LOT NO. 6032, 1 TRADEMART DRIVE, KOWLOON BAY, KOWLOON

QUANTITATIVE RISK ASSESSMENT FOR EXISTING LPG FILLING STATIONS

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CHAPTERS

TABLES

FIGURES

APPENDICES

EXECUTIVE SUMMARY

The Application Site is proposed in the Kowloon Bay area and bounded by roads on east (Kwun Tong Bypass and Trademart Drive), north (Kai Cheung Road) and southwest (Kai Fuk Road) sides.

A Quantitative Risk Assessment (QRA) has been prepared to assess risk posed by the existing LPG Filling Stations in the vicinity of the Subject Site and recommendations for mitigation measures, protection works and other measures and works to be carried out, if necessary, is recommended within the Subject Site to ensure compliance with the risk guidelines as described in Section 4.4, Chapter 12 of the Hong Kong Planning Standards and Guidelines (HKPSG). Key study findings are summarized as below:

Individual Risk

The individual risk contour of 10^{-5} per year does not reach the LPG Filling Station. Therefore, it could be concluded that the individual risk of the LPG Filling Stations are in compliance with the Hong Kong Government Risk Guidelines.

Societal Risk

The societal risks (F-N curves) of the LPG Filling Stations during Operation Phase (2029) are within the "Acceptable" region. Therefore, it could be concluded that the societal risk associated with the LPG Station during Operation Phase (2029) are in compliance with Hong Kong Government Risk Guidelines.

Conclusions

The individual risk and societal risk associated with LPG Filling Stations are in compliance with Hong Kong Risk Guidelines, no further mitigation measures are required.

As a good matter of engineering practice, it is recommended to ensure the effectiveness of fire protection system, fire-fighting system and the associated safety management system for the proposed development in compliance with the engineering standards and codes.

1. INTRODUCTION

1.1 Project Background

The background in relation to the project and this Section 16 planning application is included in the planning statement.

Ramboll Hong Kong Limited is commissioned by the applicant to prepare this Quantitative Risk Assessment with respect to operations of existing LPG filling stations in the vicinity of the Application Site.

1.2 Application Site and its Environment

The Application Site is located in Kowloon Bay area with surrounding context described under Section 2.1.1 of the planning statement. To the immediate south is an area zoned open space and the further Petrol and LPG filling station. It is at the western fringe of Kowloon Bay commercial area. Kai Fuk Road is connecting to the existing Kai Tak Tunnel with tunnel portal located on west side of the Application Site. The planned Central Kowloon Route would have the future alignment running along and to the further southwest.

The surrounding area consists of new office developments, ageing industrial buildings, GIC uses, bus depot, school, hotel, open space/ playground, etc.

The Application Site itself is currently occupied by existing KITEC development with nearly 100% building footprint.

1.3 Proposed Development

Residential, retail, office and GIC developments are proposed at the Application Site.

- There is an exhibition/ multi-purpose hall, office tower, mixed blocks, which includes hotel commercial and showrooms, and 4 residential towers (Tower 1 to 5, with Tower 4 omitted). Ancillary facilities include car park, clubhouse (with 1 outdoor swimming pool) for residential portion, E&M rooms, etc.
- There are altogether 1,494 flat units provided.
- The GFA of exhibition related uses & showroom, retail, office, hotel, Government, Institution or Community facilities and kindergarten are respectively 23,273 m^2, 13,403 m^2, 35,600 m^2, 24,000 m^2, 2,090 m^2 and 557m^2, respectively.
- There will be a kindergarten housed in podium building, day care centre for elderly (DCCE), social work service for pre-primary institutions (SWSPPI) and residential care home for the elderly (RCHE) housed in commercial arcade.
- The tentative completion year is 2029.
- Layout and floor plans of the proposed development are given in **Figure 4-1.**

1.4 Objective and Scope of Work

The objective of this QRA Study is to demonstrate if the risk levels posed by the existing LPG Filling Station, located in vicinity of Proposed Development in Kowloon Bay, are still in compliance with Hong Kong Risk Guidelines in Berms of individual risk and societal risk.

The scope of work for this QRA Study:

- LPG Filling Stations in vicinity of Proposed Development in Kowloon Bay.

The following scenarios were assessed in this QRA Study:

- Operation Phase – to consider the LPG Filling Station and the off-site surrounding population (population outside the subject LPG Filling Station and within the study zone of 200m) in 2029 upon operation of the proposed development

The detailed tasks are summarized as follow:

- To identify all credible hazards associated with the LPG Filling Station and its operation activities to the off-site population;
- To conduct a QRA study to quantify off-site population risk in terms of both individual risk and societal risk;
- To compare the identified risk profiles against with Hong Kong Risk Guidelines; and
- To identify and recommend practical and cost effective risk mitigation measures, if required.

This QRA Study is limited to the risks associated with LPG Filling Station, which have potential risks to cause fatalities to off-site population. The transportation of LPG by LPG road tankers outside the LPG Filling Station is outside the scope of work of this QRA Study.

It is also noted that according to HKSAR Government's climate action plan 2050, zero vehicular emissions and zero carbon emissions in the transport section before 2050 is aimed at. The provision of LPG filling stations may be redundant in future and corresponding risk impact should no longer be an issue afterwards.

2. PROPOSED QUANTITATIVE RISK ASSESSMENT METHODOLOGY

The elements of this QRA Study are depicted in **Figure 2-1**, and each of the elements is depicted as follows:

2.1 Hazard Identification

This QRA Study concerns the fire and explosion hazards associated with the LPG Filling Stations and usage at the LPG Filling Stations. The associated failure may be partial or catastrophic as a result of corrosion, fatigue, etc. These failures are taken into account in this detailed QRA Study.

2.2 Frequency Analysis

This task involves the frequency analysis for each of the identified hazardous scenarios. Frequency analysis includes quantification of the frequency of the initiating events (e.g. pipework failure), and conducting event tree analysis to model the development of an event to its final outcomes (flash fire, jet fire, fire ball, toxicity if not being ignited).

2.3 Consequence Analysis

Consequence analysis involves the modelling of the physical effects, and SAFETI 8.9, was adopted in this QRA Study. Consequence modelling results were used to establish levels of harm to critical equipment at varying distances from the identified hazards. Probit equations are used to relate levels of harm to exposure.

2.4 Risk Summation and Assessment

Risk summation was conducted using SAFETI 8.9 which calculates the risk based on different failure outcomes, failure event location, and weather conditions prevailing proximity to the LPG Filling Stations. This step involves the integration of consequence and frequency data to give the risk results in terms of the required risk measures.

The products of the frequency and consequence for each outcome event above are summed and the total risks are expressed in individual risk and societal risk terms. Individual risk results were presented as iso-risk contours overlaid on the LPG Filling Stations plot plan. The acceptability of the risks for the off-site population was compared with Hong Kong Risk Guidelines.

Examples of recently completed studies with respect to LPG filling stations based on same methodology include: "Quantitative Risk Assessment of Proposed Rezoning of Tung Chung Traction Substation and Adjacent Areas for Residential Use" prepared in June 2023.

2.5 Risk Mitigation

Practical and cost-effective risk mitigation measures based on this QRA Study are recommended, if required, to demonstrate the risks are ALARP.

3. LPG FILLING STATIONS DESCRIPTION

3.1 Proposed Residential Development

The two LPG Filling Stations, located in vicinity of Proposed Development in Kowloon Bay, are depicted at **Figure 3-1**.

3.2 LPG Filling Station Description (Shell)

The LPG Filling Station consists of one (1) 25.4 kL (~14 tonnes) underground LPG storage vessel installed in an individual concrete chamber filled with washed sand. Under normal operations, the LPG storage vessel is filled approximately, ~12-tonne, 85% of the maximum capacity. The storage vessel is covered with corrosion protection coating, 100% radiography tested and fully stress relieved. It is designed, manufactured and tested in accordance with the requirements of Gas Standards Office (GasSO) of Electrical and Mechanical Services Department, the Hong Kong Government.

Based on the layout plan, the underground storage vessel is installed southbound of the LPG Filling Station and it is replenished by 9-tonne LPG road tankers to top up maximum 85% capacity of storage vessel through connection points northbound of the station. A dedicated LPG road tanker unloading bay is provided for parking during unloading operations. Road tankers were estimated to enter the LPG Filling station 700 trips annually and the average residence time is typically around 120 minutes, including 10 minutes for setting-up and parking away the refilling equipment; and 110 minutes for off-loading operation.

Twin nozzles are installed at each of the two (2) LPG dispenser and each nozzle has capacity of 750 kg/ hr for consumers. The dispensers are located westbound of the LPG Filling Station, adjacent to the underground LPG storage vessel.

3.3 LPG Filling Station Description (Sinopec)

The LPG Filling Station consists of two (2) 16 kL (~9 tonnes) underground LPG storage vessel installed in an individual concrete chamber filled with washed sand. Under normal operations, the LPG storage vessel is filled approximately, ~7.65-tonne, 85% of the maximum capacity. The storage vessel is covered with corrosion protection coating, 100% radiography tested and fully stress relieved. It is designed, manufactured and tested in accordance with the requirements of Gas Standards Office (GasSO) of Electrical and Mechanical Services Department, the Hong Kong Government.

Based on the layout plan, the underground storage vessel is installed southbound of the LPG Filling Station and it is replenished by 9-tonne LPG road tankers to top up maximum 85% capacity of storage vessel through connection points northbound of the station. A dedicated LPG road tanker unloading bay is provided for parking during unloading operations. Road tankers were estimated to enter the LPG Filling station 559 trips annually and the average residence time is typically around 120 minutes, including 10 minutes for setting-up and parking away the refilling equipment; and 110 minutes for off-loading operation.

Twin nozzles are installed at each of the two (2) LPG dispenser and each nozzle has capacity of 750 kg/ hr for consumers. The dispensers are located westbound of the LPG Filling Station, adjacent to the underground LPG storage vessel.

4. SURROUNDING POPULATION AND METEOROLOGICAL DATA

4.1 Proposed Development

The tentative completion year of the proposed development is year 2029, and the layout of the proposed development is depicted at **Figure 4-1**. The total population of the proposed development is assumed to be 9,616, and the breakdown of the population is presented in the following table.

Development Parameters	Proposed Development										
	Residential	Clubhouse	Hotel	Retail	F&B	Office	Exhibition related uses & showroom	Kindergarten	Day Care Unit	RCHE	SWSPPI
Number of flats	1,494		720								
Assumed Area (m2)	-		24,000	10,723	2,680	35,600	23,273	557	365	1,560	165
Assumed Population	4,034	99	1,440 Guest 768 Staff Total 2,208	375	137	1,958	512	120 Students 15 Staff Total 135	30 Elderly 12 Staff Total 42	60 Residents 51 Staff Total 111	5

The proposed development maintains separation in compliance with requirement in Ch 12 of the HKPSG (i.e. 15 m from commercial building; 55 m from residential building to LPG filling station).

4.2 Surrounding Population

The surrounding population within the proposed study zone of the LPG Filling Station, including building and traffic population, is summarised in **Appendix 4-2**. The majority of the population is contributed from the nearby commercial and industrial buildings, etc.

Proposed Study Zone

A proposed study zone of 200 m from the LPG storage vessel at the LPG Filling Stations is adopted for this QRA Study based on other previous QRA Studies results. The proposed study zone is depicted at **Figure 3-1**.

The population data within the proposed study zone was estimated based on online available population data (e.g. population census, traffic census, etc.). Detailed approaches to building and traffic population are elaborated below.

Type of Population

Three (3) types of population were considered in this QRA Study:

- Pedestrian population on footpaths and pavements next to hazardous facilities;
- Road traffic population; and
- Building population.

The population estimation methods for each type of population are outlined in the following section. For areas not supported by surveys or where information is not available from other pertinent sources of information, the assumptions were made based on consultant's best judgment.

Pedestrian Population

Pedestrian flow on the pavement was assessed by a site survey conducted in December 2024. The site survey was aimed to collect site specific information such as the width of pavement, surrounding conditions of the public traffic roads etc. The results from the survey were analysed and used to calculate population densities for all pavements within the proposed study zone. Based on the population data from the site survey, the population density can be calculated from:

$$\text{Pedestrian population (persons m}^{-2}\text{)} = P / t / v / W$$

where:

P	is the number of pedestrians passing a given point (person);
t	is the total time the survey is carried out (second);
W	is the pavement width (m); and
v	the average walking velocity of pedestrian (m s^{-1}).

Road Traffic Population

Road traffic population on the public roads was estimated from a combination of the following databases:

- Site survey in December 2024; and
- Annual Traffic Census 2023 (ATC 2023)/5/ (latest available census data at the time of preparation of this report)

A population density approach was adopted for estimating the population within vehicles on the road. The traffic density information adopted in this QRA Study was estimated based on the data in ATC 2023 to determine the distribution of vehicle types. The road population density can be calculated:

$$\text{Population Density (persons/m}^2\text{)} = AADT * P_{avg} / 1{,}000 / 24 / V * L$$

where:

AADT	is Annual Average Daily Traffic from 2020 Annual Traffic Census;
P_{avg}	is the average number of persons per vehicle;
V	is the vehicle speed in km hr^{-1}; and
L	is the road length in meter, based on actual road length data.

The average number of persons per vehicle can be calculated:

$$P_{avg} = \sum_{i=1}^{N} (f_i \times P_i)$$

where:

f_i	is the fraction of vehicle type i (based on ATC 2023); and
P_i	is the mean occupancy of vehicle type i (based on ATC 2023).

Typically, vehicle speed of 50 km hr^{-1} for non-highway route sections and vehicle occupants were conservatively assumed as outdoor with regards to consequence models (i.e. flash fire/ toxic cloud, etc.).

Land and Building Population

The population within the proposed study zone was based on site survey and the following data:

- 2022 Population By-Census;

- Home Affairs Department (HAD), the Government of the Hong Kong Special Administrative Region;
- Planning Data from Town Planning Board;
- Centamap (2023); and
- Geographic Information System (GIS) database (2023 data).

Based on 2022 Population By-census, the average domestic household size in Kwun Tong District is 2.7.

For population that could not be achieved by above approaches, estimation followed the generic assumption in approved "EIA Study for Operation of the Existing Tai Lam Explosive Magazine at Tai Shu Ha, Yuen Long for Liantang/ Heung Yuen Wai Boundary Control Point Project, Register No.: AEIA-193/2015" for both existing buildings and approved developments.

Buildings within or extended partly into the proposed study zone were also included in this QRA Study. Rather than considering density based averages of population, the analysis was based on individual buildings which led to a more conservative results. The task of assessing population building-by-building is substantial and necessary to accurately model the F-N pairs with high N values.

Building Identification

The Lands Department (LD) of the HKSAR Government maintains a GIS database of buildings in Hong Kong. To identify buildings within the proposed study zone, a recent GIS map layer containing all buildings (LD) is obtained. Additionally, the GIS building height information for most of the buildings (but usually not podiums or other similar structures) are available from the same source.

Building Attributes, Usage and Population Identification

There is no publicly available data on the population of individual buildings in Hong Kong. Therefore, to provide a basis for estimating the number of people in a building, it is necessary to identify each building's attributes and usage.

The buildings and structures in the GIS database are classified as: regular building (BP), building under elevated structure (BUP), open-sided structure (OSP), proposed building (PBP), podium (PD), podium under elevated structure (PDU), ruin (RU) and temporary structure (TSP). Using the above information, the information from property developers' websites as well as aerial photographs, the actual or likely usage category of buildings identified is determined and each building is assigned to one of the following building usage categories:

- Administrative/Commercial Building;
- Car Park;
- College;
- School;
- Industrial Building;
- Leisure;
- MTR station/Bus terminus;
- Residential Building;
- Station such as Petrol Station; and
- Fire Station.

It is noted that unless their usage could be determined from other available sources, the GIS categories OSP, TSP and RU, will be assumed to be unpopulated.

Following this, the same information sources are used to sub-categorise buildings by other attributes, such as the number of floors. Details on the building attributes and categories and associated assumptions are presented below.

Number of Floors

For some commercial/industrial buildings and most of the high-rise residential buildings (excluding the housing estates), the floor number information, considered more accurate, is available from the owner and property developer websites. When the above information is not available and where it will be possible, the number of floors will be estimated from 3-dimensional aerial photos. In the event of an absence of data from any of the above sources, such buildings are covered by site survey carried out.

Other Buildings

While residential type buildings are well defined, less information is available for other types of buildings such as commercial, industrial, etc. The approach to estimate other building population generally follows that adopted in the EIA Study[/22/], and is based on typical Hong Kong building structure, usage, height, and typical capacity of public facilities. The details are presented in Table 4.1 . In the application of typical values from Table 4.1, further refinements will be made based on building height and area and taking into account the maximum density of people in most non-residential building as one person per 9 m^2 (the Code of Practice for the Provision of Means of Escape in Case of Fire[/24/]).

Table 4.1 Building Population Assumptions (other than the Proposed Development)

Category	**Building Height /Size(1)**	**Assumption**			**Total**
Car Park		Basic assumptions are listed below. In some cases the car park population will be adjusted based on the building area. For car parks located in podiums of residential, commercial or industrial buildings, the podium population will be assumed as 1% of the population of associated buildings.			
		Parking Levels	Parking Spaces	People/Parking Space	
	H	5	40	0.2	40
	L	1	20	0.2	4
Petrol Station		It is assumed that, there are 2 staff stationed in the convenience shop, 4 stationed in fuel area for filling, and 4 vehicles each with 3 people, parked into the Petrol Station for petrol filling			18
Industrial Building		Floors	Units	People/unit	
	H	25	8	8	1,600
	M	15	6	8	720
	L	8	6	6	288
Administrative/ Commercial		Floors	Units	People/Unit	
	H	10	20	2	400
	M	5	20	2	200
	L	2	10	2	40
Leisure	H	200 people for large sized leisure facility			200
	M	100 people for medium sized leisure facility			100
	L	50 people for small sized leisure facility			50
	LL	10 people for very small sized leisure facility			10

Note:
(1) Legend for Building Height/Size
- H for Tall/Large, 40 storeys;
- M for Medium, 20 storeys;
- L for Low/Small, 3-storey; and
- LL for Very Low/Very Small

Using the above approach, a database providing characterisation of each building by their broad attributes including population was developed.

Time Period and Occupancy

Since population can vary during day and night time periods, the analysis considered three (3) time categories. These are summarised in **Table 4.2**.

Table 4.2 Population Time Periods

Time Period	Description
Weekday Day	7am to 7pm, Monday – Friday
Weekend Day	7am to 7pm, Saturday – Sunday
Night	7pm to 7am, Monday – Sunday

The occupancy of buildings during each time period was based on assumptions as listed in **Table 4.3**. For vehicle and pavement populations, distribution across various time periods was based on site surveys.

Table 4.3 Population Distribution

Type	Occupancy (%)		
	Weekday Day	**Weekend Day**	**Night**
Leisure (1)	70%	100%	0%
Carpark (1)	70%	70%	10%
Residential Building (1)	50%	80%	100%
Construction Site	100%	50%	0%
Petrol Station (1)	50%	50%	1%
School/Clinic (1)	100%	10%	0%

Notes:

1. Based on site survey observations and ERM project experience.

2. Population occupancy based on Harbour Area Treatment Scheme Stage 2A EIA[/2/]

3. Population occupancy base on MTRCL SCL EIA[/3/]

*4. For population time period, refer to **Table 4.2***

5. Based on previously approved QRA Study for Towngas Transmission Network 2012[/19/]

Sources of Ignition

Flammable gas cloud from an accidental LPG release can be ignited if ignition sources are present in the close vicinity or on the migration path of the cloud, leading to a fire or an explosion. If the gas cloud is diluted outside the flammable concentration range (i.e. below lower flammable limit (LFL)), or the ignition source is not present, it will disperse and disappear with no fire hazards to the surroundings. The energy level, timing, location and ignition effectiveness of ignition sources in the vicinity of the LPG Filling Station affect the extent of gas cloud dispersion and its potential impacts.

Three (3) types of ignition sources are defined in the SAFETI 8.9 risk model.

Population polygons are defined to account for human activities such as smoking, cooking, and using electrical appliances, which are assigned implicitly to all population groups by SAFETI 8.9.

Transportation route segments are defined for the moving vehicles on roads. Its ignition probability is calculated from its traffic density, average vehicle speed, vehicle ignition efficiency and total length of the road.

Protection Factors

Protection factors[/4/] are used to factor down the population so that only those exposed to hazardous scenarios are considered in the risk summation. Three (3) types of protections were considered in this QRA Study:

Height Protection Factors

Partial or full height of the surrounding buildings (high-rise and low-rise) could be affected by a fireball and a boiling liquid expanding vapour explosion (BLEVE) considering their size and lift-off (90 m).

The maximum height of the vapour cloud could reach almost up to 30 m in its transient state, therefore only the lowest ten (10) floors of the buildings (assume 3 m per floor) would possibly be encompassed.

The vapour cloud dispersed from a horizontal pressurised jet release could extend to up to three (3) m. In this analysis, the affected height is conservatively assumed as five (5) m, i.e. the lowest two (2) floors are affected.

Indoor Protection Factors

Protection for indoor population against thermal radiation and flash fire is considered by assuming that the indoor fatality rate is 10% of the outdoor fatality rate.

For persons within the fireball radius/ criteria zone, it was assumed that 50% of person would be killed and 50% indoor protection factor was applied in this QRA Study.

Shielding Protection Factors

A shielding factor is generally used to take credit for the shielding of buildings by other buildings from fire effects. A shielding factor of 50% is applied only to these buildings located behind the closest buildings for fireball scenario.

4.3 Meteorological Data

The proximity weather station to the LPG Filling Station is Kai Tak Weather Station. As per the latest meteorological data from Kai Tak Weather Station in 2021, the analysis results between 2017 and 2021 were still valid. Therefore, wind speed, wind stability and direction data between 2017 and 2021 taken from Kai Tak Weather Station were adopted for this QRA Study.

With reference to "Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)", at least six (6) representative weather classes are recommended for this QRA Study, covering the stability conditions of stable, neutral and unstable, low and high wind speed. At least the following six (6) weather classes have to be covered in terms of Pasquill classes.

Stability class	Wind speed (1)
B	Medium
D	Low
D	Medium
D	High
E	Medium
F	Low

Note: Low wind speed corresponding to 1 – 2 m s-1
Medium wind speed corresponding to 3 – 5 m s-1
High wind speed corresponding to 8 – 9 m s-1

The details of meteorological data analysis can be referred to Assumption 1.1.1 in **Appendix 4-1 .**

The probability of each weather state for each direction during the day and night are rationalized for analysis based on the requirements presented in "Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)". Based on the analysis on raw data, the summary of meteorological data is shown in, which was used for this QRA Study.

The wind speeds are quoted in units of meters per second, (m s−1). The atmospheric stability classes refer to:

A – Turbulent

B – Very Unstable

C – Unstable

D – Neutral

E – Stable

F – Very Stable

Atmospheric stability suppresses or enhances the vertical element of turbulent motion. The vertical element of turbulent motion is a function of the vertical temperature profile in the atmosphere. The greater the rate of decrease in temperature with height, the greater the level of turbulent motion. Category D is neutral and neither enhances nor suppresses turbulence.

Table 4.4 Meteorological Data from Kai Tak Weather Station (Year 2017 – 2021)

	Probability												
	Day						Night						
Wind Speed (m s−1)	3.1	1.7	3.1	7.0	3.0	1.5	1.0	1.6	4.1	7.2	3.0	1.5	
Direction (degree) / Atmospheric Stability	B	D	D	D	E	F	B	D	D	D	E	F	Total (%)
0	0.50	0.21	0.37	0.02	0.07	0.23	0.00	0.04	0.22	0.05	0.34	1.03	3.09
30	0.62	0.27	0.52	0.03	0.17	0.33	0.00	0.08	0.38	0.01	0.64	1.42	4.46
60	0.80	0.15	0.68	0.08	0.06	0.12	0.00	0.05	0.64	0.05	0.39	0.85	3.88
90	3.09	0.28	5.58	1.36	0.39	0.24	0.00	0.07	6.57	1.03	2.84	1.81	23.25
120	5.85	0.82	5.48	0.46	0.72	0.84	0.00	0.07	4.05	0.33	2.88	5.81	27.31
150	3.00	0.70	0.97	0.02	0.16	0.70	0.00	0.07	0.16	0.01	0.53	4.61	10.92
180	1.07	0.42	0.22	0.00	0.01	0.20	0.00	0.04	0.08	0.00	0.14	1.94	4.13
210	1.73	0.32	0.23	0.00	0.01	0.16	0.00	0.03	0.13	0.00	0.22	1.24	4.07
240	2.81	0.38	1.00	0.06	0.06	0.25	0.00	0.04	0.90	0.02	0.59	2.15	8.28
270	0.77	0.20	0.38	0.02	0.04	0.21	0.00	0.06	0.28	0.02	0.22	1.26	3.47
300	0.67	0.31	0.73	0.03	0.10	0.31	0.00	0.09	0.50	0.01	0.37	1.09	4.22
330	0.50	0.20	0.43	0.00	0.08	0.19	0.00	0.06	0.33	0.00	0.30	0.83	2.92
Total (%)	21.41	4.26	16.59	2.08	1.86	3.79	0.00	0.71	14.26	1.54	9.46	24.04	100.00

5. HAZARD IDENTIFICATION

5.1 Hazards of LPG Facilities

Properties of LPG

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

Events Leading to an Accidental LPG Release

Historical accident records such as Major Hazard Incident Data Service (MHIDAS) database, and previous QRA Study reports were reviewed. The main hazard associated with the LPG Filling Stations is an accidental uncontrolled release of LPG resulting in a fire or an explosion upon an 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.;
- Loading failure, i.e. an LPG release occurs as a direct result of the road tanker unloading operation;
- Refuelling failure, i.e. an LPG release occurs during LPG refuelling operation; and
- External events such as earthquake.

1. Storage Vessel Failure

Failure of the storage vessel may result from:

- Spontaneous cold catastrophic failure leading to an instantaneous release of full inventory;
- Spontaneous partial failure (25 mm hole leak) leading to a continuous release of the full inventory;
- Over-pressurisation due to an accidental overfilling during unloading from the LPG road tanker; and
- External events such as earthquake.

2. Road Tanker Failure

Failure of the LPG road tanker may result from:

- Spontaneous cold catastrophic failure leading to an instantaneous release of full inventory;
- Spontaneous partial failure (25 mm hole leak) leading to a continuous release of the full inventory, and;
- Accidents during unloading caused due to collision by another vehicle in the LPG Filling Stations.

3. Pipework Failure

Spontaneous failure of the LPG pipework is possible due to material defects, corrosion, fatigue and erosion. Most of the LPG pipework is installed aboveground, which includes the liquid-inlet pipework for LPG unloading to the storage vessel, the liquid supply line from the vessel to vaporisers and the vapour pipe from the vessel and vaporisers to the distribution network outside the LPG Filling Stations. Pipework may fail in an earthquake. Part of the liquid-inlet pipework for LPG unloading to the storage vessel is installed above ground, which may subject to failure due to impact of the LPG road tanker.

4. Dispenser Failure

Spontaneous failure of the dispenser is possible due to material defects, corrosion, fatigue and erosion. Failure of the dispenser is also possible due to an impact of the vehicle in the LPG Filling Station for refuelling.

5. Refuelling Flexible Hose Failure

An accidental release from the flexible hose may be caused by spontaneous failure due to material degradation, fatigue, corrosion and erosion. It can also be resulted from the unloading operation:

- Hose misconnection error, an error by the driver/ operator failing to properly connect the loading hose and the hose coming adrift during unloading;
- Hose disconnection error, an error where the driver/ operator inadvertently disconnects the hose while the valve is still open or has failed open; and
- Road tanker drive-away error, an error where the driver inadvertently drives the tanker away during unloading
- Impact to the refuelling vehicle by another vehicle in the LPG Filling Station, which causes movement of the refuelling vehicle leading hose disconnection and hose damage.

6. Submersible Pump Failure

Leak from the submersible pump itself will result in a release of LPG back to the storage vessel and therefore any hazard is not expected. A release is possible from the flange associated with the fitting of the pump on the top of the storage vessel. This will results in a liquid leak from a 25 mm hole, equivalent to the space between two (2) bolt holes on a flanged joint.

7. External Events

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

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

Safety Provision

Various safety provisions are installed in the LPG Filling Stations upon the safety guidelines requirements of the Gas Authorities of EMSD, Code of Practice of Hong Kong LPG Industry. These provisions can act in different combinations to prevent or mitigate the hazards due to an accidental LPG release. In this project, the following safety provisions are provided.

a. Non-return Valve

Non-return valve on the liquid filling line can prevent back flow from the LPG storage vessel.

b. Excess Flow Valve

Excess flow valve installed at the tanker, storage vessel is used to stop the liquid flow when a large release occurs (e.g. a guillotine failure of the pipe/ hose).

c. Breakaway Coupling

It is possible that the LPG road tanker or vehicle may be driven away while the hose is still connected, which may cause damage to the LPG facilities and lead to an LPG release. The breakaway coupling is installed to prevent the LPG spillage due to tanker/ vehicle drive-away during unloading/ refuelling operation.

d. Double-check Filler Valve

Double-check filler valve is installed at the LPG filling point to prevent the release back from the storage vessel.

e. Pressure Relief Valve

Pressure relief valve is installed on the LPG road tanker and storage vessel to protect against excessive pressure built-up due to overfilling or over-heating by an external fire. The excessive pressure may cause a leak or catastrophic failure of the LPG road tanker and storage vessels.

f. Manual Isolation Valve

Manual isolation valves are installed on the LPG road tanker, storage vessel and pipework for the operators/ drivers to close the manual valve in case of a failure or for maintenance operation.

g. Chartek Coating

Chartek coating is a safety feature for the LPG road tankers in Hong Kong. It was reported that the coating could give a protection for at least thirty (30) minutes in case of jet fire impingement. The coating can prevent formation of hot spots on the LPG road tanker upon a jet fire impingement, which induces thermal weakening of the tanker wall and leads to a BLEVE scenario.

h. Emergency Shutdown System

The LPG storage, unloading and refilling will be stopped and isolated by the emergency shutdown (ESD) system, which is activated manually by fireman.

i. Leak Detection System with Alarm

Flammable gas detectors are installed near the LPG filling point, LPG storage vessel, LPG dispenser and the office. Alarm will be initiated and activated upon a detection of a flammable vapour cloud.

j. Emergency Shutdown System

The LPG storage, unloading and refilling will be stopped and isolated by the emergency shutdown (ESD) system, which is activated by manually press emergency bush button or automatically if any dispenser malfunction.

k. Water Spray System

Water spray system is provided, which is automatically activated by infra-red detection system as well as the manual push handle.

l. Dry Powder Fire Extinguishers, Sand Buckets and Fire Hydrant

Dry powder fire extinguishers, sand buckets and fire hydrant are provided for general fire-fighting uses.

m. Emergency Response Plans

Emergency response plans are enacted in accordance with the Code of Practice for Hong Kong LPG Industry.

n. Fire Services

Fire brigade is available within a few minutes upon an emergency call in case of a fire. BLEVE scenario could be prevented by effective fire-fighting measures by the well trained fire-fighters

Outcome of an Accidental LPG Release

The following outcomes could result from an accidental LPG release:

- Jet fire;
- Flash fire;
- Vapour Cloud Explosion (VCE);
- Fireball; and
- Boiling Liquid Expanding Vapour Explosion.

Catastrophic failure of the LPG vessel and road tankers may lead to a fireball, a flash fire or an VCE. Vessel/tanker partial failure (leak), pipework / flexible hose failure may cause a jet fire, a flash fire or an VCE. Potential fire escalation to a BLEVE scenario is considered if a jet fire impinges on the road tanker over a period of time, causing the formation of hot spots on the road tanker wall and subsequent a structural failure. The LPG storage vessel in the LPG Filling Stations is underground in a concrete compartment filled with washed sand. Fireball and escalation to a BLEVE scenario are considered unlikely for such tank.

If an ignition source is not present in the vicinity of the LPG vapour cloud or along the migration path of the cloud with the wind, the LPG vapour cloud will dissipate and no hazardous impact is expected.

LPG Hazardous Release Scenarios

Representative LPG accidental release scenarios to be considered in this QRA Study are summarised in Table 5.1

Table 5.1 Accidental LPG Release Scenarios Considered

Equipment	Failure Type	Release Type	Potential Hazardous Outcomes
LPG storage vessel	Catastrophic failure	Instantaneous	Flash fire, VCE
	Partial failure (leak)	Continuous	Flash fire, VCE, Jet fire
LPG road tanker	Catastrophic failure	Instantaneous	Flash fire, VCE, fireball
	Partial failure (leak)	Continuous	Flash fire, VCE, Jet fire
Liquid-inlet pipeline	Guillotine failure	Continuous	Flash fire, VCE, Jet fire, BLEVE
	Leak	Continuous	Flash fire, Jet fire
Liquid supply line to dispenser	Guillotine failure	Continuous	Flash fire, VCE, Jet fire
	Leak	Continuous	Flash fire, Jet fire
Dispenser	Guillotine failure	Continuous	Flash fire, Jet fire, BLEVE
Flexible hose to vessel	Guillotine failure	Continuous	Flash fire, VCE, Jet fire, BLEVE
	Leak	Continuous	Flash fire, Jet fire
Flexible hose to vehicle	Guillotine failure	Continuous	Flash fire, Jet fire, BLEVE
Submersible Pump Flange	Leak	Continuous	Flash fire, VCE, Jet fire, BLEVE

Failure of the underground vapour return line is not further considered in this QRA Study because the LPG vapour release can only impact a few meters from the leak source, thus only imposes risk to the on-site population at the LPG Filling Station.

Failure of LPG vehicle (taxi / minibus) is not further considered in this QRA Study due to the small tank inventory, which is about 95.5 to 103.5 L and 122 L for the LPG taxies and minibuses respectively. Such a small inventory could only sustain a short duration of the LPG release, resulting in insignificant impacts at the LPG Filling Station compared with releases from the pipework/ hose connected to the LPG storage vessel/ road tankers.

6. FREQUENCY ANALYSIS

6.1 Overview

Frequency analysis involved estimation of likelihood of LPG containment failure leading to an accidental LPG release and subsequent outcome probabilities. The initiating failure probabilities were estimated from the historical accident statistics, published failure data report, industrial testing results and professional judgement [/4//9//10//11/.] Base failure frequencies of LPG facilities (vessels, pipework, etc.) were 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 into account of severity of the release event and surrounding environment. Frequency analysis in this QRA Study takes into account previous QRA Studies [/4/].

6.2 Base Failure Frequencies

<u>Base Initiating Failure Frequencies</u>

Storage Vessel Failure

Storage vessel failure refers to a cold catastrophic failure leading to an instantaneous release of the whole inventory or a cold partial failure causing a continuous leakage. 1.8×10^{-7} per vessel year and 5.0×10^{-6} per vessel year are adopted for cold catastrophic and partial failures, respectively. The vessel is stress relieved and 100% radiograph tested.

It is assumed that the vessel inventories would be nominally full (80% maximum capacity of vessel) in 20% of time and there is nominal 60% vessel inventory in 80% of the time.

Road Tanker Failure

LPG road tanker can be regarded as a mobile LPG storage vessel. The cold spontaneous failure rate for LPG road tankers could be higher than for a fixed storage vessel because of stresses experienced by the road tanker due to vibration during transportation, and cyclic loading associated with unloading of the road tanker. The catastrophic and partial failure probabilities of a LPG road tanker are 2.0×10^{-6} and 5.0×10^{-6} per year, respectively.

LPG road tankers will generally stay in the LPG Filling Stations for 60 minutes per delivery, in which the first and last 5 minutes are used as setting up the equipment. As such, inventories of the road tankers are assumed to be full in 4.2% of time, 50% in 91.6% of time and 0% in 4.2% of time.

Dispenser Failure

LPG from the storage vessel is pumped to the dispenser for the vehicle refuelling operation. The typical dispenser in Hong Kong is a metering device, a hose with self-sealing connector, four (4) ball valves (with two (2) flanges for each valve) and a certain length of a rigid pipework. Failure of the dispenser is estimated as 7.9×10^{-5} per year by "Parts Count" approach as illustrated in Table 6.1. The pipework in the dispenser has a diameter of 20 mm. Only significant leak is considered in this QRA Study.

Table 6.1 Failure Rate of LPG Dispenser

Item	Quantity, no. or m	Base failure rate, per year or per m.year	Fraction of significant leak (>0.2 D)	Failure rate, per year
Pipe (1)	2	2.5×10^{-5}	15%	7.5×10^{-6}
Ball valve (2)	4	8.8×10^{-5}	6%	2.1×10^{-5}
Flange (1)	10	5.0×10^{-6}	100%	5.0×10^{-5}

Pipework Failure

Failure of LPG pipework can be a guillotine failure (full bore rupture) and a partial failure (a leak from pipe cracks). For LPG Filling Stations, a leak from pipework is considered insignificant contributors to the overall risk levels. Nevertheless, a leak from pipework (pipe diameter 50 mm or above) is included in this analysis for the conservatism. The generic guillotine failure rate of LPG pipework is taken as 10^{-6} per meter per year, and the rate of partial failure (equivalent to 10% pipe diameter) is taken as 3.3 times of the guillotine failure rate, i.e. 3.3×10^{-6} per meter per year. It should be noted that failure of pipework cannot result in uncontrolled continuous release of LPG unless isolation fails, i.e. simultaneous failure of safety equipment (non-return valve, excess flow valve and ESD valve) and manual shut-off valves.

Flexible Hose Failure

A cold spontaneous failure of a flexible hose may occur during the road tanker unloading or vehicle refuelling operation. Likelihood of a guillotine failure is taken as 9.0×10^{-8} per hour. Average residence time of the LPG road tanker at the LPG Filling Stations is about 60 minutes, therefore the guillotine failure rate of the unloading flexible hose is estimated to be $9.0 \times 10^{-8} \times 60 / 60 = 9.0 \times 10^{-8}$ per operation. Partial failure of an unloading flexible hose to vessel (hose diameter 38 mm) is also considered in this QRA Study. Similarly, a failure rate of 3.3 times the guillotine failure rate is applied.

Road Tanker Unloading Operation

Hose Misconnection Error

A misconnection error could occur if the hose is improperly connected to the filling point. A failure rate of 3×10^{-5} per operation is adopted in this QRA Study. It is assumed the error causes the hose to come completely apart, leading to a full-bore release.

Hose Disconnection Error

This error is caused by 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 2×10^{-6} per operation is adopted in the analysis, assuming it results in a full-bore release.

Road Tanker/ vehicle Drive-away Error

A drive-away error could occur due to an inadvertent drive-away before completion of replenishment. A full-bore release is assumed in this QRA Study. The probability of drive-away error before operation completion is deemed low and a failure rate of 4×10^{-6} per operation is adopted.

Road Tanker Impact onto LPG Facilities

The road tanker may strike the LPG Filling Stations during truck manoeuvring within the LPG Filling Stations, causing damage to the LPG Filling Stations or the road tanker. A likelihood of 1.5×10^{-4} per operation is adopted for this human error. The road tanker moves very slowly 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 and rear protection bumper) for the vessel, fittings, valves and pipework fitted to it. The probability of damaging the filling pipework is considered very low as it is protected by a steel framework and the vehicle bumper, minimising the chance and energy of direct tanker impact on the pipework. A release from the damaged pipework could ensue only if the driver neglects his duty to check the pipework integrity and possible leakage before unloading starts.

Road Tanker Collision during Unloading

The LPG road tanker is parked in a designated unloading bay of the LPG Filling Stations with fencing forming an area with limited access. The collision by other vehicles to an unloading road tanker is considered very unlikely, nevertheless, a frequency of 10^{-8} per operation is used in this QRA Study.

Damage due to Tanker/ Vehicle Impact

Compared with normal road accidents, an inadvertent impact by the road tanker/ vehicle to the LPG facilities is deemed to be a low speed/ momentum collision due to provision of speed limit, sufficient lighting, well-maintained concrete floor, warning signage, and supervision of working staff, etc. at the LPG Filling Station. Mostly it will cause slight damage, which is not potential to result in an uncontrolled LPG release.

Road traffic accident statistics from the Transport Department shows 83% of all road accidents in Hong Kong are slight collision, 16% (take 20% in the aforementioned calculation) are serious collision and 1% is fatal collision. Most of the road accidents are related to speeding, crossing the road, drunk/ drug drive, poor road condition, bad weather, etc. In this QRA Study, it is assumed fatal accidents have the potential to cause a catastrophic rupture of the tanker, a guillotine failure of the LPG pipework/ dispenser/ flexible refuelling hose, and serious accidents have the potential to cause leakage of the tanker/ pipework. To account for the aforementioned provisions at the LPG Filling Station, a modification factor of 0.5 is conservatively applied, i.e. the probability of fatal and serious damage in an impact accident at the LPG Filling Station is taken as 1% x 0.5 = 0.5% and 20% x 0.5 = 10%, respectively. For the liquid-inlet pipework at the LPG filling point, a modification factor of 0.1 is applied considering the extra protection from the crash barrier around the unloading area, i.e., the probability of 0.1% and 2% is adopted for fatal and serious damage in an impact accident.

Table 6.2 Road Traffic Accidents by Severity (2000 – 2016)

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Fatal	162	167	162	173	160	139	135	153	143
Serious	2,838	3,165	3,118	2,674	2,519	2,504	2,315	2,376	2,096
Slight	11,949	12,299	12,296	11,589	12,347	12,419	12,399	12,786	12,337
Total	**14,949**	**15,631**	**15,576**	**14,436**	**15,026**	**15,062**	**14,849**	**15,315**	**14,576**
Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
Fatal	126	114	128	116	128	99	117	129	2351
Serious	1,943	2,052	2,190	2,385	2,476	2,508	2,510	2,379	42,048
Slight	12,247	12,777	13,223	13,393	13,485	13,183	13,543	13,591	215,863
Total	**14,316**	**14,943**	**15,541**	**15,894**	**16,089**	**15,790**	**16,170**	**16,099**	**260,262**

Storage Vessel Overfilling/ Overpressurisation

During the unloading operation the driver should stay close to the road tanker while his assistant should monitor the filling in progress at the LPG vessel. The vessel shall not be filled more than 85% of the total volume[/26/]. Each bulk storage vessel is equipped with two (2) gauges for indicating the quantity of content, one (1) is the level indicator and the other is the pressure indicator. In Hong Kong, it is an offence to overfill an LPG storage vessel, and the possibility is considered to be 2×10^{-2} per operation. However, even if overfilling occurs, a release due to overpressurisation will not occur unless all of the following failures take place:

- Failure of truck pump overpressurisation protection system;
- Failure of pressure relief valve on the storage vessel; and
- Failure of the driver and his assistant to activate ESD system and close manual shut-off valves.

Considering the design pressure of the LPG storage vessel is 17.25 barg (around 3.7 times of the normal operating pressure of 4.6 to 4.7 barg in summer), the outcome of storage vessel overfilling/ overpressurisation is mostly probably the leak from the vessel connections. Nevertheless, a catastrophic rupture of the vessel may not be ruled out. Historical records in the MHIDAS database (1950 – 2006) on vessel overfilling show that 3 in 123 incidents led to a catastrophic rupture of the storage vessel which accounts for about 2.4% of all incidents. In this QRA Study, the probability of a catastrophic rupture is assumed as 2.5%.

Human Error

In case of an accidental failure, it is very probable that the on-site staff can rectify the problem before and after any hazard event occurs. Two (2) competent persons (the driver and the assistant) are required to be engaged in the whole unloading process and stay in close vicinity of the road tanker and the filling point during the whole unloading operation. They are suitably trained in the unloading operation, first aid, firefighting and emergency response, and equipped with necessary personal protection equipment (PPE). 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". Upon an accidental LPG release from the LPG road tanker, the driver and the assistant will immediately terminate the unloading operation by pressing the ESD button on the tanker, and close the shut-off valves on the tanker. If there is an accidental LPG release from the LPG pipework or the LPG dispenser and its associated hoses, alarm will be raised by the leak detection system, the on-site working staff will stop and isolate the LPG filling system by pressing the ESD button in the office or at the dispenser. The failure to start the ESD system of the LPG road tanker/ the LPG Filling Station by pressing the ESD button under an emergency situation is taken as 0.1 for failure to act correctly at a stressful emergency situation.

At the LPG Filling Station, an isolation of LPG unloading/ refuelling pipework and LPG dispensers can be activated by all ESD buttons by staff at the LPG Filling Station. Therefore, the failure probability for two (2) or more staff to activate the ESD system for an isolation is estimated as 0.01 (= 0.1 x 0.1) in an emergency situation. Probability of human error becomes much higher under emergency situations when a hazard event occurs, the operator has to take immediate actions to rectify the problem under extreme stresses, and also possibly puts himself in some danger from the LPG release. This chance of human errors in this case is 0.3 for general rate for errors involving very high stress levels. Nevertheless, a more conservative probability of 0.5 is adopted in this QRA Study considering the operators are facing the dangers from an accidental LPG release.

Failure of Safety Provisions

Hazards from an accidental LPG release can be prevented or mitigated by the safety provisions at the LPG Filling Station. The following failure probabilities in **Table 6.3** are assumed based on "QRA methodology for LPG Installations"[/4/] and "Lees"[/10/].

Table 6.3 Failure of Safety Provisions

Item	Failure probability
Excess Flow Valve (LPG vessel)	1.3×10^{-2} per demand
Excess Flow Valve (LPG road tanker)	1.3×10^{-2} per demand
Non-Return Valve	1.3×10^{-2} per demand
ESD Trip System Fails	10^{-4} per demand
Breakaway Coupling	1.3×10^{-2} per demand
Double-Check Filler Valve	2.6×10^{-3} per demand
Chartek Coating under Jet Fire Attack	10^{-1} per demand
Fire Service to Prevent BLEVE (Jet Fire Impingement on the Road Tanker)	5×10^{-1} per demand
Pressure Relief Valve	10^{-2} per demand
Truck Pump Over-pressure Protection System (LPG Road Tanker)	10^{-4} per demand

External Events

Earthquake

Hong Kong is situated on the southern coast of mainland China and facing the South East China Sea. Hong Kong is not located within the seismic belt and 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. Buildings and infrastructures in Hong Kong are designed to withstand earthquakes up to Modified Mercalli Intensity (MMI) VII.

It is estimated that MMI VIII is of sufficient intensity to cause damage to specially designed structures. In this QRA Study, it is assumed that such earthquake may result in storage vessel leakage and pipework rupture at a probability of 0.01[/13/]. The probability of earthquake occurrence at MMI VIII and higher in Hong Kong is very low comparing with other regions and is estimated to be 10^{-5} per year[/4/].

Aircraft Crash

The LPG Filling Stations are far away from the Hong Kong International Airport. The frequency of aircraft crash was estimated using the Health & Safety Executive methodology[/14/], which was adopted in previous QRA study of an LPG Storage Installation. The number of flights from 1999 to 2017 is extracted from the Civil Aviation Department[/15/], and extrapolated to year 2017 by linear regression. The calculated impact frequency due to aircraft crash is in the order of magnitude lower than 10^{-9} per year. It is therefore not further considered in this QRA Study.

Car Crash

The LPG Filling Stations are surrounded by concrete boundary wall, railings and fence. A buffer area with bollard and railings along road side is provided on the side to the public access road in the vicinity of the LPG Filling Stations. It is considered car crash on the public road impacts negligible threat to the LPG Filling Stations.

Severe Environmental Events

Loss of containment due to severe environmental events such as typhoon or tsunami (large scale tidal wave) is considered unlikely since the LPG vessel is installed underground in a mounted concrete compartment. The LPG Filling Station is designed safe to withstand the wind load for typhoon. The site is not threatened by tsunami since it is far away from the shore. Therefore the risk is deemed unlikely and not further considered in this QRA Study.

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 LPG facilities in the LPG Filling Stations is extremely low as it is next to industrial/residential buildings. It is deemed lighting strike is remote, therefore not further considered in this QRA Study.

Dropped Object

The chain link fence and aboveground facilities of the LPG Filling Stations are sheltered by the roof. Thus, it is considered the threat from dropped objects to the LPG Filling Stations is remote and not further assessed in the analysis.

Subsidence

Excessive subsidence may lead to a 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. Besides, the ground condition of the LPG Filling Stations is stable, risk from subsidence is therefore deemed remote and not further considered.

External Fire

External fire refers to the occurrence of a fire event outside the LPG Filling Stations which may lead to the failure of the LPG facilities. This might be expected from road accidents on the public road, probably involving car crash or 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. However, the LPG Filling Stations are separated from the main road by a buffer area, and the key facilities inside are further protected by concrete building structures (e.g. the LPG vessel compartment) and activation of emergency shutdown system for potential external fire threat. The risk of escalation by an external fire to the LPG facilities is deemed remote and not further considered in this QRA Study.

Estimated Base Failure Frequencies

Base failure frequencies of hazardous events are derived by fault tree analysis from the initiating failures and summarised in **Table 6.4** and **Table 6.5**.

Table 6.4 Base Failure of Hazardous Events for Sinopec LPG Refilling Station (LPG A)

Hazardous Event	Failure Frequency (per year)
Cold Catastrophic Failure of LPG Road Tanker (100% Full)	4.58E-08
Cold Catastrophic Failure of LPG Road Tanker (50% Full)	1.83E-07
Cold Partial Failure of LPG Road Tanker (100% Full)	2.08E-07
Cold Partial Failure of LPG Road Tanker (50% Full)	8.30E-07
Failure of Flexible Hose to Vessel (rupture) (100% Full)	2.36E-06
Failure of Flexible Hose to Vessel (rupture) (50% Full)	9.42E-06
Failure of Flexible Hose to Vessel (leak)	2.49E-05
Failure of Liquid-Inlet Pipework (rupture)	1.21E-08
Failure of Liquid-Inlet Pipework (leak)	2.00E-06
Cold Catastrophic Failure of LPG Vessel (100% Full)	7.26E-08
Cold Catastrophic Failure of LPG Vessel (50% Full)	2.90E-07
Cold Partial Failure of LPG Vessel (100% Full)	2.04E-06
Cold Partial Failure of LPG Vessel (50% Full)	8.17E-06
Failure of Liquid Supply Line to Dispenser (rupture)	1.06E-07
Failure of Liquid Supply Line to Dispenser (leak)	1.50E-06
Failure of Dispenser	1.86E-05
Failure of Vapour return pipework from Dispenser to Vessel (rupture)	1.01E-05
Failure of Vapour return pipework from Dispenser to Vessel (leak)	3.30E-05
Failure of Flexible Hose to Vehicle (rupture)	3.71E-04
Failure of Submersible Pump Flange (leak)	1.52E-07

Table 6.5 Base Failure of Hazardous Events for Shell LPG Refilling Station (LPG B)

Hazardous Event	Failure Frequency (per year)
Cold Catastrophic Failure of LPG Road Tanker (100% Full)	5.73E-08
Cold Catastrophic Failure of LPG Road Tanker (50% Full)	2.29E-07
Cold Partial Failure of LPG Road Tanker (100% Full)	2.60E-07
Cold Partial Failure of LPG Road Tanker (50% Full)	1.04E-06
Failure of Flexible Hose to Vessel (rupture) (100% Full)	2.95E-06
Failure of Flexible Hose to Vessel (rupture) (50% Full)	1.18E-05
Failure of Flexible Hose to Vessel (leak)	3.12E-05
Failure of Liquid-Inlet Pipework (rupture)	1.52E-08
Failure of Liquid-Inlet Pipework (leak)	2.50E-06
Cold Catastrophic Failure of LPG Vessel (100% Full)	3.67E-08
Cold Catastrophic Failure of LPG Vessel (50% Full)	1.47E-07
Cold Partial Failure of LPG Vessel (100% Full)	1.05E-06
Cold Partial Failure of LPG Vessel (50% Full)	4.19E-06
Failure of Liquid Supply Line to Dispenser (rupture)	1.06E-07
Failure of Liquid Supply Line to Dispenser (leak)	1.50E-06
Failure of Dispenser	3.52E-05
Failure of Vapour return pipework from Dispenser to Vessel (rupture)	1.01E-05
Failure of Vapour return pipework from Dispenser to Vessel (leak)	3.30E-05
Failure of Flexible Hose to Vehicle (rupture)	4.60E-04
Failure of Submersible Pump Flange (leak)	1.52E-07

6.3 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 various factors such as a release type (an instantaneous or a continuous type), ignition sources and ignition probabilities, and degree of congestion to cause a VCE.

SAFETI 8.9's built-in event trees are used to calculate the frequencies of hazardous outcome scenarios.

Catastrophic Failure of LPG Road Tanker and Storage Vessel

For a catastrophic failure (tank catastrophic rupture scenario) of the LPG road tankers and LPG storage vessel and, the associated event trees are depicted in **Figure 6-1**, **Figure 6-2** and **Figure 6-3** respectively. Immediate ignition is assumed a probability of 0.5 for a large releases following Purple Book, as shown in **Table 6.6**.

For road tankers, immediate ignition results in a fireball, as the content would be instantly released to the ambient. For LPG storage vessel installed in a sand-filled concrete compartment, the probability of a fireball is negligible and therefore its effect is not evaluated. Instead flash fire is considered under this circumstance.

A probability of 0.5 is assigned to a delayed ignition, which may produce a flash fire or a VCE. The occurrence of a VCE requires an ignition of a dispersed gas cloud present in a confined or congested space. Given the relatively open nature of the surroundings of the LPG Filling Stations, an explosion probability of 0.2 is conservatively assumed in this QRA Study.

Table 6.6 Ignition Probabilities from Purple Book

Source		Ignition Probability
Continuous	Instantaneous	
< 10 kg s^{-1}	< 1,000 kg	0.2
10 – 100 kg s^{-1}	1,000 – 10,000 kg	0.5
> 100 kg s^{-1}	> 10,000 kg	0.7

Leak from LPG Storage Vessel / Road Tanker

For a partial failure (a leak) of the LPG road tankers and LPG storage vessel, a lower probability of 0.2 is adopted for an immediate ignition from **Table 6.6**. Immediate ignition of a continuous pressurised release results in a jet fire. Similar probabilities are assumed for the delayed ignition, which could also lead to a flash fire or a VCE. The associated event trees are depicted in **Figure 6-4** and **Figure 6-5**.

It is possible a jet flame from an aboveground pipe/ hose/ vaporiser failure may impinge on the road tanker and cause tank failure over a period of time. The probability of flame impingement is assumed as 1/6 for the liquid inlet pipework and flexible hose of the road tanker. For the flexible filling hose to vehicle, a direction probability of 1/12 is assumed based on the LPG Filling Stations layout, and the fraction of residence time of the LPG road tanker is also considered for fire impingement. In Hong Kong the LPG road tankers are protected by a layer of Chartek coating, preventing the formation of hot spots above the liquid level of the tank. The probability of coating failure is assigned as 0.1. Consideration is also given to fire services which may be ineffective in preventing a BLEVE, and the probability is assumed as 0.5. The mounted LPG storage vessel is free from flame impingement. The associated event trees of the aboveground pipe/ hose/ vaporiser failure leading to a BLEVE are presented from **Figure 6-6** to **Figure 6-8** respectively.

Leak from Underground Pipe

Vertical jet release is considered for an underground release. BLEVE due to a jet fire impingement on the LPG road tanker wall is not considered as the LPG tank is protected by the vehicle chassis. The associated event trees of an underground pipe are presented in **Figure 6-9** and **Figure 6-10,** respectively.

6.4 Knock-on Effect from Surrounding LPG Filling Stations

In additional to the process equipment failures associated with the LPG Filling Stations, the knock-on effect (the additional risk, such as the escalated fireball event from the LPG road tanker) from the surrounding LPG Filling Stations were also considered and included for the QRA Study. The knock-on effect (the additional risk) from the surrounding LPG Filling Stations were identified from the individual risk contours of each surrounding LPG Filling Station.

7. CONSEQUENCE ANALYSIS

The consequence analysis was conducted in two (2) steps:

- Source term modelling to determine the release rate, duration and quantity; and
- Physical effects modelling to determine the gas dispersion, fire and explosion effects zone based on the output of source term modelling.

The impact of the hazardous outcomes on the surrounding population was analysed. In this QRA Study, the simulation software SAFETI 8.9 was employed to calculate the hazardous release and the effects zones.

7.1 Source Term Modelling

LPG is modelled as a mixture of 70% butane and 30% propane. LPG stored in a storage tank is pressurised to medium pressures to reach an equilibrium state between the liquid and vapour phases, depending on ambient temperatures. In the analysis maximum allowable inventory is conservatively assumed at the time of failure, i.e. 11 tonnes for LPG storage vessel and 9 x 85% = 7.65 tonnes for LPG road tankers. Instantaneous release of the whole inventory is assumed for a catastrophic rupture of LPG tanks. For a continuous release, a discharge rate is calculated by SAFETI 8.9 based on the leak size, release temperature, release pressure, and fluid phase. Duration of discharge is determined by discharge rate and total inventory.

7.2 Physical Effects Modelling

Gas Dispersion

The dispersion model in *SAFETI 8.9* was used for the dispersion of unignited vapour cloud following an accidental LPG release. The model takes into account various transition phases, from dense cloud dispersion to buoyant passive gas dispersion, in both an instantaneous release and a continuous release.

LPG vaporises rapidly upon a release. A number of possible outcomes may occur depending on whether the vapour is ignited immediately or ignited after a period of time. The dispersion characteristics are influenced by meteorological conditions and material properties, such as density of the vapour cloud.

Fire scenarios of different kinds may be developed in the presence of ignition sources in the proximity of a LPG release. Flash fire could occur once the cloud encounters ignition sources. It may result in a VCE in a confined space or a congested area. If ignition source is not present, the vapour cloud will disperse downwind, and be diluted to the concentration below its LFL. In this case, the vapour cloud would become too lean to be ignited and have no harmful effect.

Jet Fire

For flammable fluids stored under pressure (pressurised storage or from liquid height above a release point), release from an orifice will become a flame jet (i.e. jet fire) when ignited immediately. The combustion of the jet is influenced by the momentum of the release.

Fireball and BLEVE

Immediate ignition of an instantaneous release of the whole inventory inside a pressurised vessel will result in a fireball. Fireball is characterised by its high thermal radiation intensity and short duration time. The principal hazard of a fireball arises from thermal radiation, which is not significantly influenced by weather, wind direction or sources of ignition. A BLEVE is similar to a fireball except that it is caused by integrity failure from a fire impingement and therefore occurs as fire escalation events. The physical effects are calculated in the same way as fireballs.

Thermal Radiation of Fires

The following Probit equation[/7/] is used to determine lethal doses for various fire scenarios.

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

where

Pr: Probit corresponding to the probability of death;

Q: the thermal radiation intensity in W m^{-2}; and

t: the exposure time in seconds.

A building is assumed to offer protection to its occupants against hazards from fires. The protection factor is assumed to be 90% for the indoor population.

Flash Fire

An LPG release will vaporise and form a vapour cloud around the release source in case not ignited immediately. This cloud will 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 will 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. Humans who are encompassed outdoors by the flash fire will be fatally injured. A fatality rate of unity is assumed for outdoor population, and 90% protection factor is assumed for the indoor occupants.

Vapour Cloud Explosion

If the vapour cloud passes through an area of congestion (e.g. cluster of pipe racks, a confined space) and gets ignited, the confinement will limit the degree of expansion of the burning cloud, causing an explosion and damage to the surroundings by the resulting overpressure. In SAFETI 8.9 the hazardous effects are modelled by two (2) concentric circular areas corresponding to heavy and light building damage, respectively. The fatality rates for persons outdoors and indoors are determined from the "Health & Safety Executive" method[/20/] and "Chemical Industry Association" (CIA) guidelines[/21/]. The fatality rates for outdoor and indoor population are presented in **Table 7.1**.

Table 7.1 Fatality Rate for Persons Outdoors and Indoors

Explosion Overpressure (barg)	Fatality Rate	
	Outdoors	Indoors
Heavy Explosion (> 0.3)	0.06	0.60
Light Explosion (>0.1 to 0.3)	0.00	0.01

7.3 Hazardous Impacts on Off-site Population

Population in the vicinity of the LPG Filling Station can be potentially affected by the hazardous events depending on the consequences. Fireball and BLEVE from the LPG road tanker have a radius of up to 59 m and a lift-off height of 118 m. LPG jet fire flame can extend up to 33 m for the road tanker leakage and 20 m for the filling hose failure. In the absence of ignition sources, the large flammable vapour cloud resulting from an instantaneous rupture of a LPG vessel or road tanker may drift downwind up to 200 m at high wind speeds. However, it is more likely the cloud would get ignited during its migration due to presence of plenty ignition sources such as moving vehicles, road lamps, and various human activities near the LPG Filling Station.

Partial or full height of the surrounding buildings (high-rise and low-rise) could be affected by fireball and BLEVE considering their size and lift-off. For people staying inside the buildings, intense thermal radiation of fireball and BLEVE would only affect the people near the window facing the LPG Filling Station, while others are protected by shielding of indoor obstacles and the building wall. The buildings facing the LPG Filling Station also provide shielding for the buildings behind.

Catastrophic failure of the storage vessel/ road tanker may lead to a large transient vapour cloud due to flashing of the pressurised flammable liquid upon a release. The transient cloud may migrate and disperse downwind away from the LPG Filling Station up to 200 m and dissipate in one (1) minute based on SAFETI 8.9 modelling. The maximum height of the vapour cloud could reach almost up to 40 m in its transient state, therefore only the lowest 14 floors of the buildings (assume 3 m per floor) would possibly be encompassed. People inside the building will not be affected by a flash fire of the transient vapour cloud due to lack of sufficient accumulation to the flammable concentration via ventilation.

The vapour cloud dispersed from a horizontal pressurised jet release could extend to up to three (3) m. In this QRA Study, the affected height is conservatively assumed as five (5) m. As a conservative approach, it is assumed that the lowest two (2) floors will be affected.

8. RISK ASSESSMENT

8.1 Risk Summation

Risk summation combines the estimation of the likelihood and consequences of hazardous events, as well as the meteorological data and population in the hazard effect zones, to give a numerical measure of risks around the fatalities. The risk analysis is conducted by the SAFETI 8.9 package and the outcome results are presented in terms of individual risk (as individual risk contours), and societal risk (as F-N curves or potential loss of life). The risk outcomes were compared with the criteria set out in the risk guidelines. Ignition sources with ignition probabilities in a given time period.

8.2 Risk Measures

The estimated off-site risk levels of hazardous installations has been compared with Hong Kong Government Risk Guidelines stipulated in Chapter 12 of the HKPSG by the Planning Department to determine the acceptability.

Societal Risk

Societal risks are presented graphically in Figure 8-1. The societal risk guideline is expressed in terms of lines plotting the frequency (F) of N or more fatalities in the off-site population from hazardous scenarios at the facility of concern. There are three areas 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 proceed; and
- **ALARP** where the risk associated with the hazardous activity should be reduced to a level "As Low As Reasonably Practicable", in which the priority of measures is established on the basis of practicality and cost to implement versus the risk reduction achieved.

Individual Risk

The maximum level of off-site individual risk associated with the hazardous installations in Hong Kong should not exceed 1 in 100,000 years, i.e. 10^{-5} per year.

8.3 Risk Results

Individual Risk

The individual risk contour of 10^{-6} per year is within the LPG Filling Stations and the individual risk contours of 10^{-7} to 10^{-9} per year for the LPG Filling Stations are presented in Figure 8-2 and Figure 8-3.

The individual risk contour of 10^{-9} per year is well confined within the proposed study zone of the LPG Filling Station; therefore, all credible hazardous scenarios with frequency above 10^{-9} per year have been well considered in this QRA Study.

Therefore, it could be concluded that the individuals risk associated with the LPG Filling Station are in compliance with the Hong Kong Government Risk Guidelines in terms of individual risk.

Societal Risk

8.3.1.1 Potential Loss of Life

The top five (5) hazardous scenarios for the LPG Filling Stations during the Operation Phase (2029) were identified and summarised at Table 8.1 and Table 8.2.

Table 8.1 Top Five (5) Hazardous Scenarios Breakdown of PLL for Operation Phase (2029) (Sinopec)

Description	PLL
Flash fire event associated with catastrophic rupture scenario of LPG Vessel during 60% full for LPG vessel	4.16E-06
Flash fire event associated with catastrophic rupture scenario of LPG Vessel during 100% full for LPG vessel	1.99E-06
Jet fire event associated with line rupture scenario of flexible hose from LPG Road Tanker to LPG Vessel during 50% full for LPG Road Tanker	1.85E-06
Fireball event associated with catastrophic rupture scenario of LPG Road Tanker during 50% full for LPG Road Tanker	1.82E-06
Flash fire event associated with line rupture scenario of flexible hose from LPG Road Tanker to LPG Vessel during 50% full for LPG Road Tanker	1.41E-06
Others	3.95E-06
Total	**1.52E-05**

Fireball event associated with catastrophic rupture scenario of LPG Road Tanker during 50% full for LPG Road Tanker

Table 8.2 Top Five (5) Hazardous Scenarios Breakdown of PLL for Operation Phase (2029) (Shell)

Description	PLL
Fireball event associated with catastrophic rupture scenario of LPG Road Tanker during 50% full for LPG Road Tanker	2.69E-06
Flash fire event associated with catastrophic rupture scenario of LPG Vessel during 60% full for LPG vessel	2.32E-06
Jet fire event associated with line rupture scenario of flexible hose from LPG Road Tanker to LPG Vessel during 50% full for LPG Road Tanker	2.11E-06
Flash fire event associated with line rupture scenario of flexible hose from LPG Road Tanker to LPG Vessel during 50% full for LPG Road Tanker	1.35E-06
Fireball event associated with catastrophic rupture scenario of LPG Road Tanker during 100% full for LPG Road Tanker	1.32E-06
Others	4.16E-06
Total	**1.39E-05**

F-N Curve

F-N curves of the LPG Filling Stations for the Operation Phase (2029) are depicted in Figure 8-4 and Figure 8-5. F-N curves reside in the "Acceptable" region; the societal risks of the LPG Filling Station during Operation Phase (2029) are in compliance with Hong Kong Government Risk Guidelines in terms of societal risk.

9. CONCLUSION

This QRA Study has been conducted to evaluate if risks associated with the LPG Filling Station are in compliance with Hong Kong Government Risk Guidelines during Operation Phase (2029).

9.1 Individual Risk

The individual risk contour of 10^{-5} per year does not reach the LPG Filling Stations. Therefore, it could be concluded that the individual risk of the LPG Filling Stations are in compliance with the Hong Kong Government Risk Guidelines.

9.2 Societal Risk

The societal risks (F-N curves) of the LPG Filling Stations during Operation Phase (2029) are within the "Acceptable" region. Therefore, it could be concluded that the societal risk associated with the LPG Station during Operation Phase (2029) are in compliance with Hong Kong Government Risk Guidelines.

9.3 Conclusions

The individual risk and societal risk associated with LPG Filling Stations are in compliance with Hong Kong Risk Guidelines, no further mitigation measures are required.

As a good matter of engineering practice, it is recommended to ensure the effectiveness of fire protection system, fire fighting system and the associated safety management system for the proposed development in compliance with the engineering standards and codes.

10. REFERENCE

Planning Department, The Government of the Hong Kong Special Administrative Region of the People's Republic of China, Hong Kong Planning Standards & Guidelines Chapter 12, Section 4.4, Hong Kong Risk Guidelines for Potential Hazardous Installations.

Drainage Services Department, Harbour Area Treatment Scheme Stage 2A Environmental Impact Assessment, 2008.

MTR Corporation Limited, South Island Line (East) Environmental Impact Assessment, 2010.

A.B. Reeves, F.C. Minah, V.H.K. Chow, Quantitative Risk Assessment Methodology for LPG Installations, Conference on Risk & Safety Management in the Gas Industry, EMSD & HKIE, Hong Kong, 1997.

Transport Department, The Annual Traffic Census 2022, August 2023.

Territory Development Department, Comprehensive Feasibility Study for the Revised Scheme of South East Kowloon Development EIA (Ove Arup & Partners HK Ltd.), July 2001.

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

Gas Authority, EMSD, Code of Practice for Liquefied Petroleum Gas Filling Stations in Hong Kong, Issue 2, November 2007.

UK Health and Safety Executive, Failure Rate and Event Data for Use with Land Use Planning Risk Assessments, 2010.

F.P. Lees, Loss Prevention in the Process Industries, Butterworth-Heinemann, 2005.

E&P Forum, Hydrocarbon Leak and Ignition Database, Report No. 11.4\180, May 1992.

Barry Kirwan, A Guide to Practical Human Reliability Assessment, CRC Press, 1994.

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

Health & Safety Executive, The Calculation of Aircraft Crash Risk in the UK, 1997.

Civil Aviation Department, Hong Kong International Airport Civil International Air Transport Movements of Aircraft, Passenger and Freight (1999 - 2015), http://www.cad.gov.hk/english/statistics.html.

2016 Population By-census, http://www.bycensus2016.gov.hk/en/.

Town Planning Board, http://www1.ozp.tpb.gov.hk/gos/default.aspx.

Environmental Resources Management, EIA for the Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities (EIA-125/2006).

Home Affairs Department, The Government of the Hong Kong Special Administrative Region, http://www.had.gov.hk/en/.

Planning Department, Projections of Population Distribution 2019 – 2028,

ERM, *Shatin to Central Link: Hazard to Life Assessment for the Transport and Storage of Explosives*, 2011 (EIA-200/2011) (ERM, 2011)

ERM, *Quantitative Risk Assessment for Towngas Transmission Network 2012*, January 2015.

N.W. Hurst, C. Nussey, R.P. Pape, Development and Application of a Risk Assessment Tool (RISKAT) in the Health and Safety Executive, Chem. Eng. Res. Des., Vol. 67, 1989.

Chemical Industry Association, Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites, 1998.

ERM, *EIA Study for Operation of the Existing Tai Lam Explosive Magazine at Tai Shu Ha, Yuen Long for Liantang/ Heung Yuen Wai Boundary Control Point Project (AEIA-193/2015)*, September 2015.

Figures

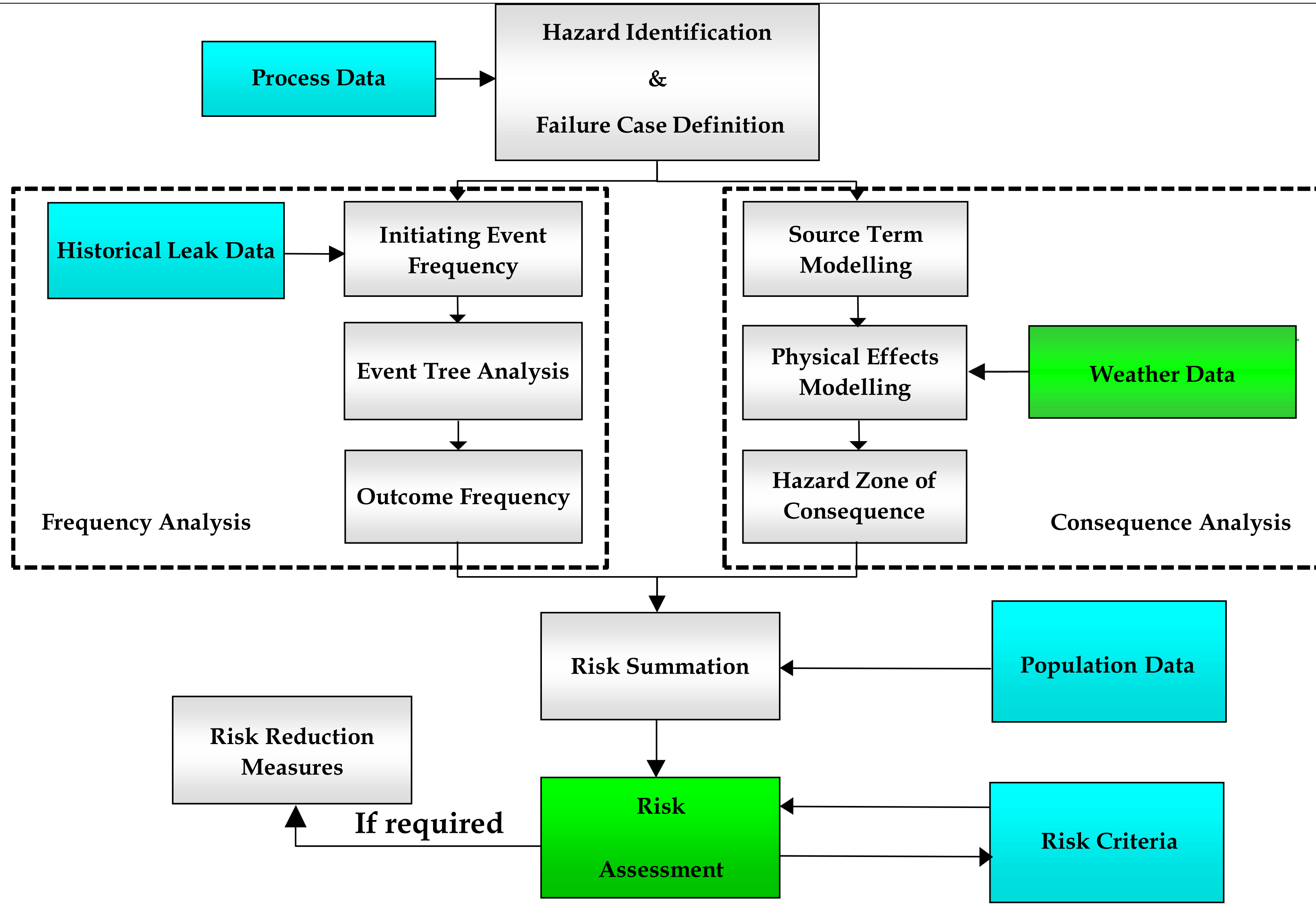

Figure: 2-1		RAMBOLL
Title: Quantitative Risk Assessment Methodology		Drawn by: VW
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Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon		Rev.: 2
		Date: Jan 2025

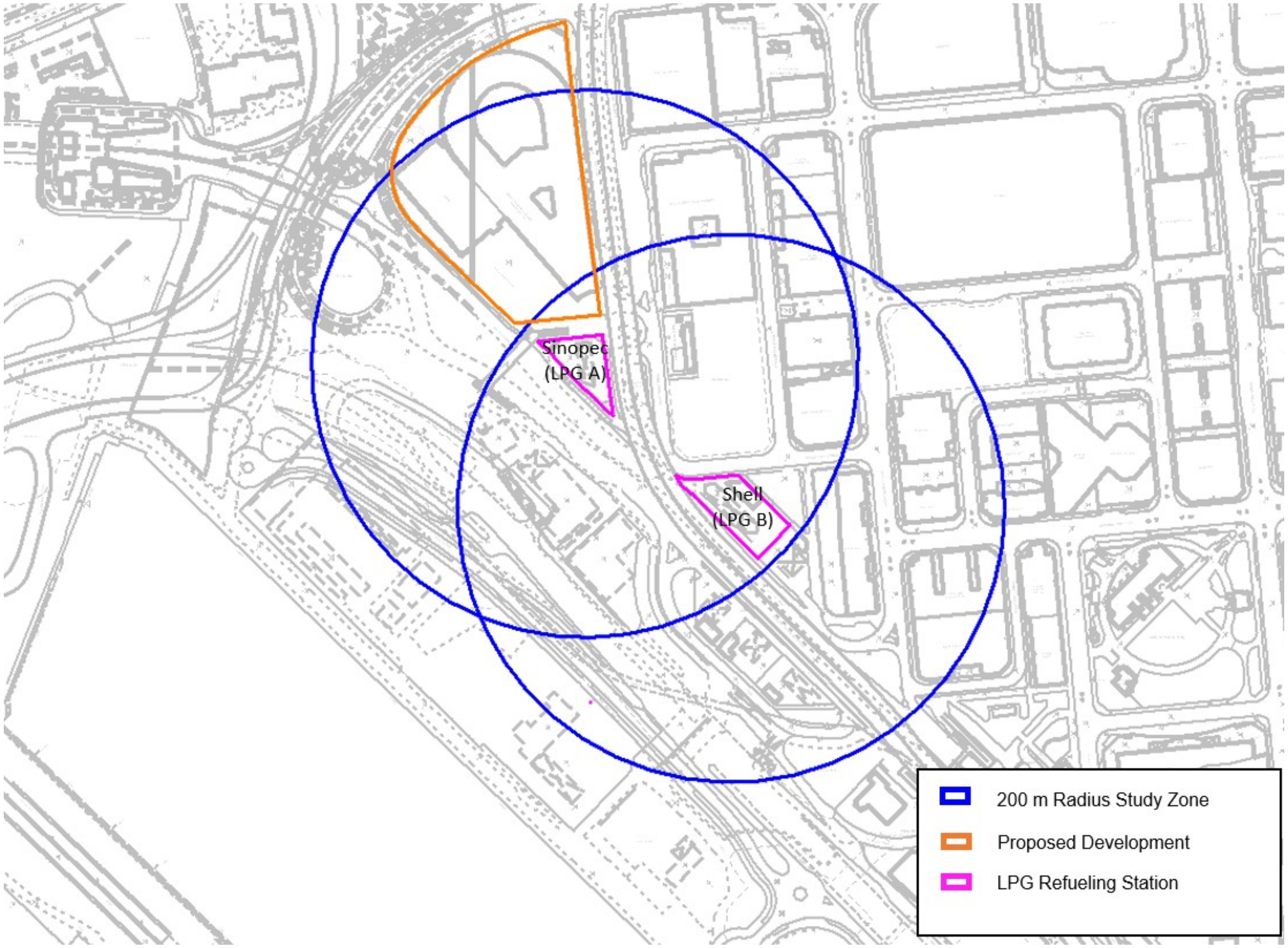

Figure: 3-1	RAMBOLL
Title: Location of the LPG Filling Stations	Drawn by: VW
	Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2
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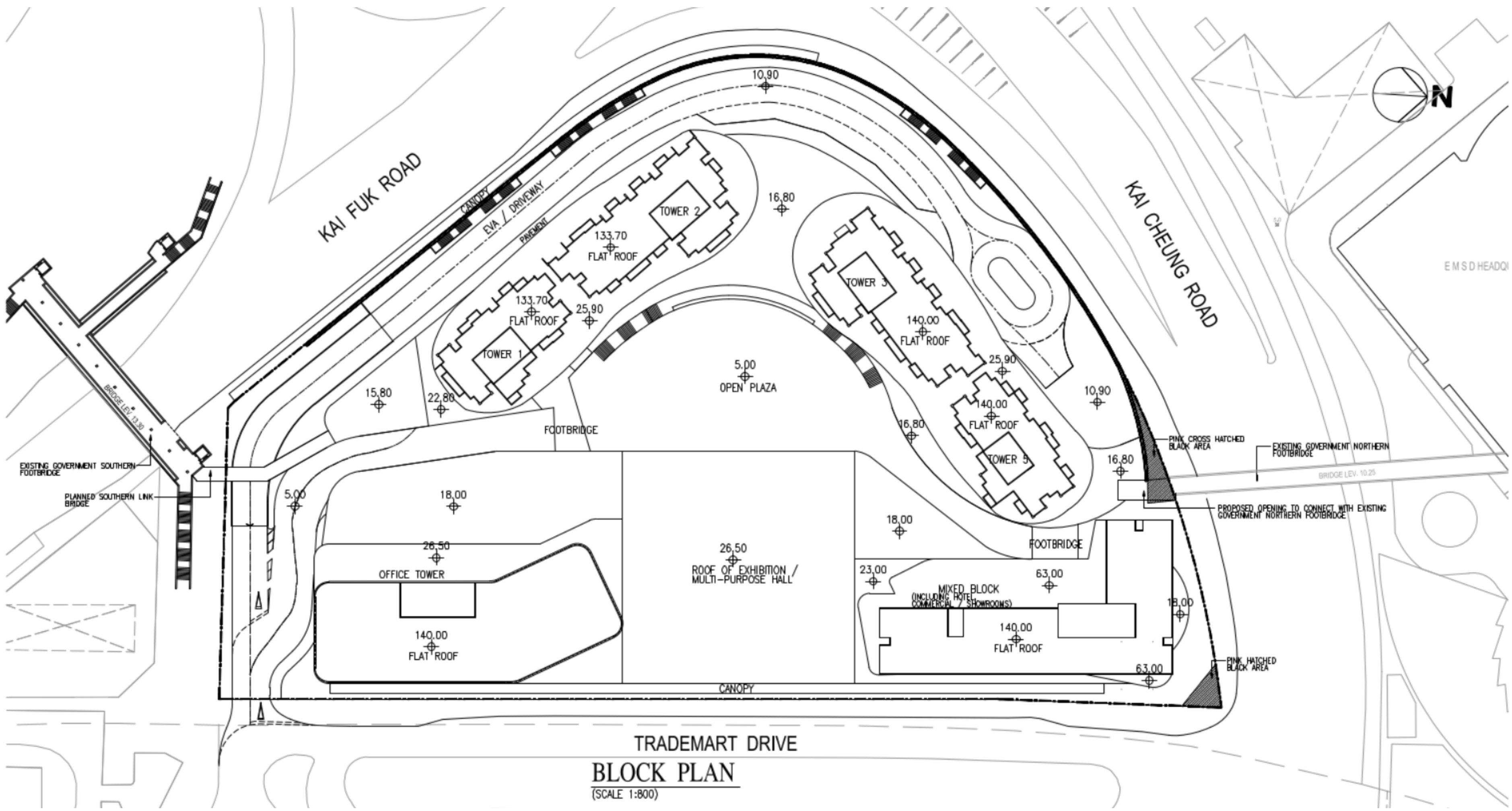

Figure: 4-1	RAMBOLL
Title: Layout of Proposed Development	Drawn by: VW
	Checked by: SP
Project: Proposed Residential (Flat), Social Welfare Facilities and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2
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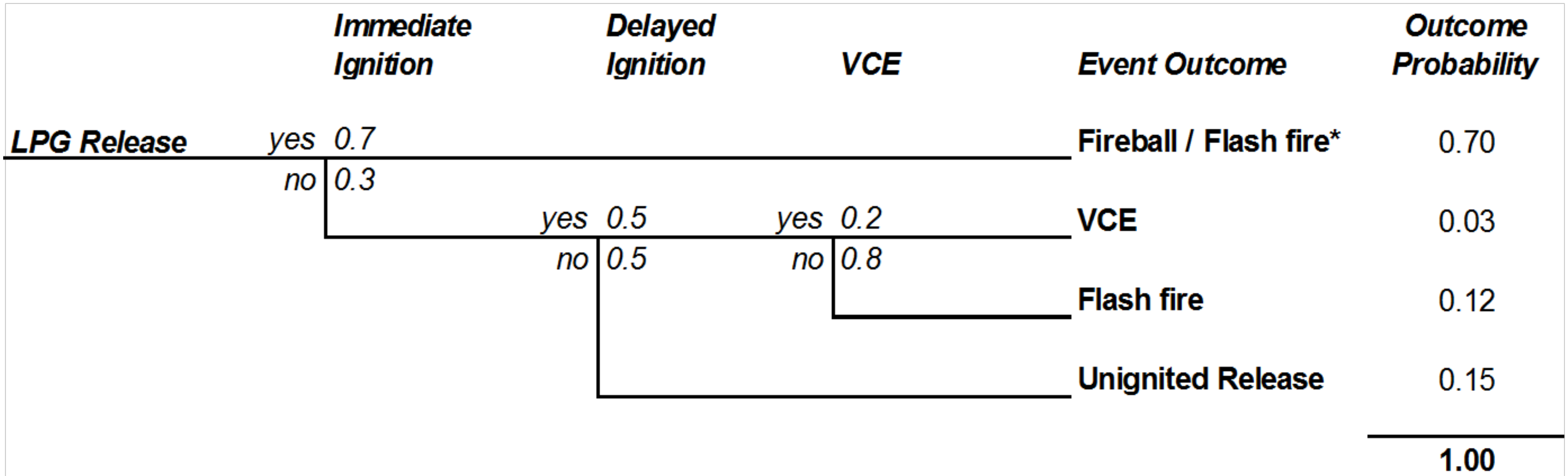

*Fireball effects are negligible for the underground storage tank. Instead Flash Fire is considered.

Figure: 6-1	RAMBOLL
Title: Event Tree for Catastrophic Failure of LPG Storage Vessel	Drawn by: VW Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2 Date: Jan 2025

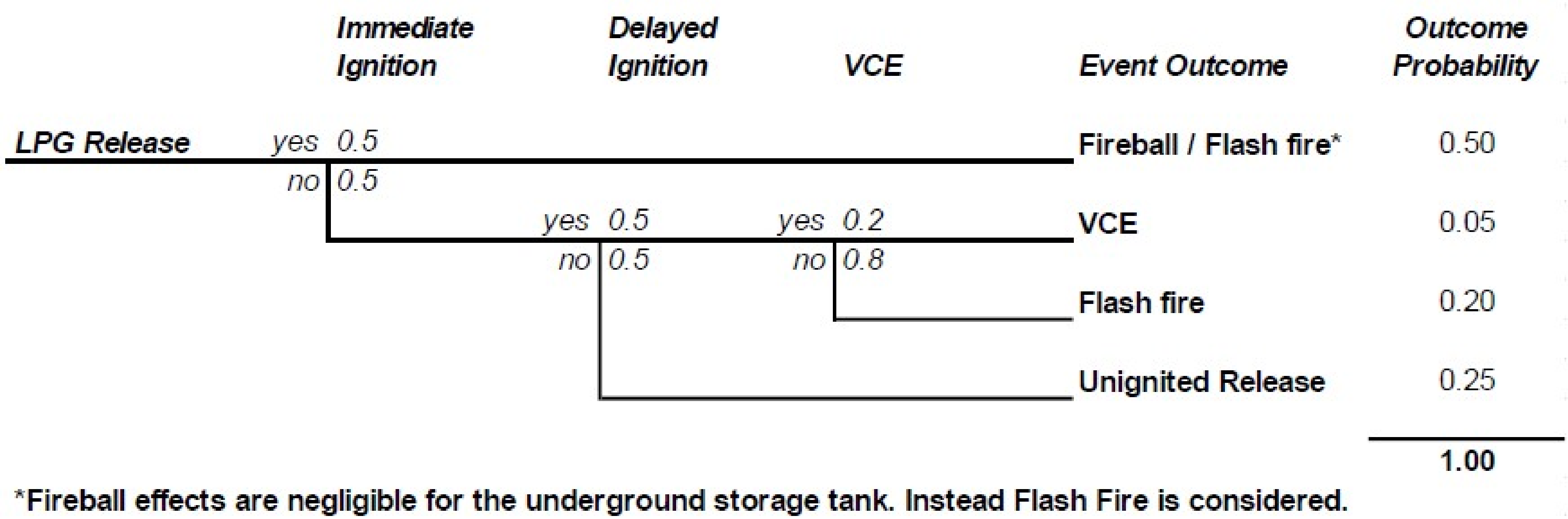

Figure: 6-2		RAMBOLL
Title: Event Tree for Catastrophic Failure of LPG Storage Vessel (60% Inventory)		Drawn by: VW
		Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon		Rev.: 2
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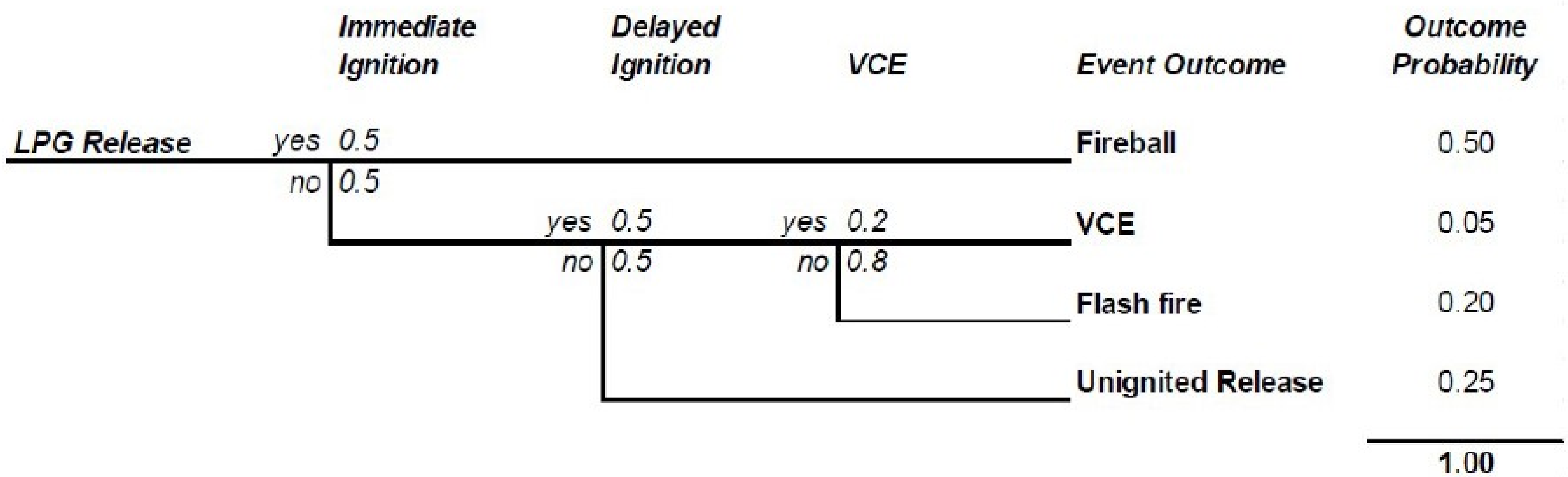

Figure: 6-3	RAMBOLL
Title: Event Tree for Catastrophic Failure of LPG Road Tankers	Drawn by: VW
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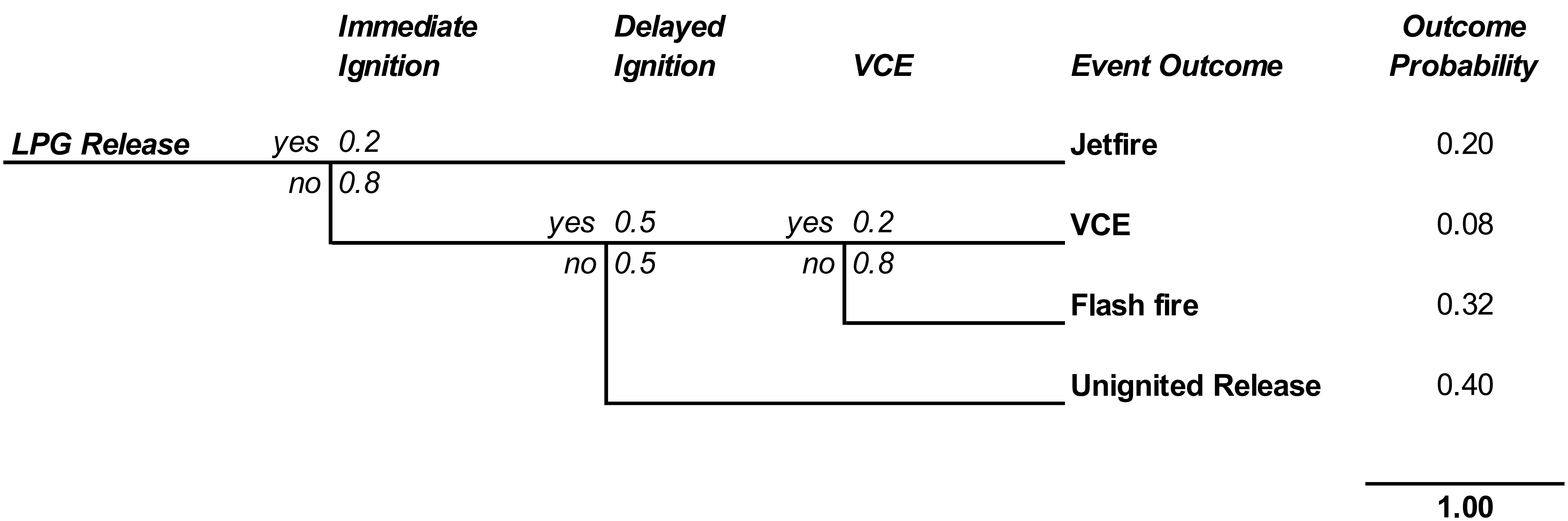

Figure: 6-4	RAMBOLL
Title: Event Tree for Partial Failure of LPG Storage Vessel	Drawn by: VW
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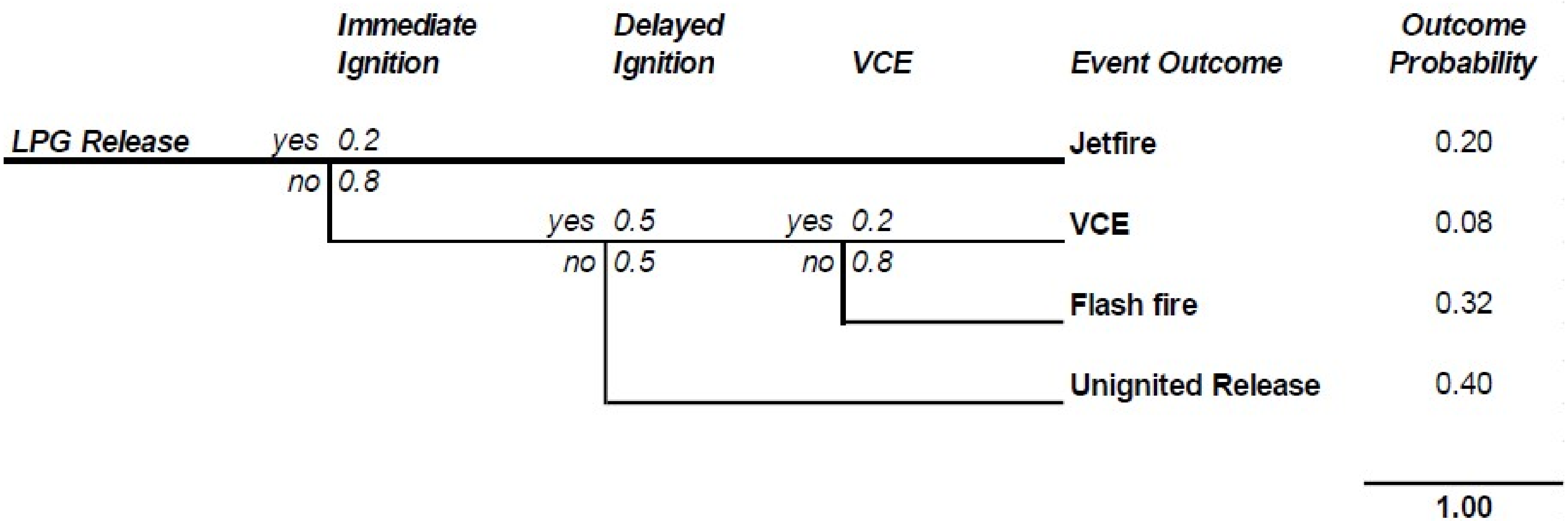

Figure: 6-5	RAMBOLL
Title: Event Tree for Partial Failure of LPG Road Tanker	Drawn by: VW
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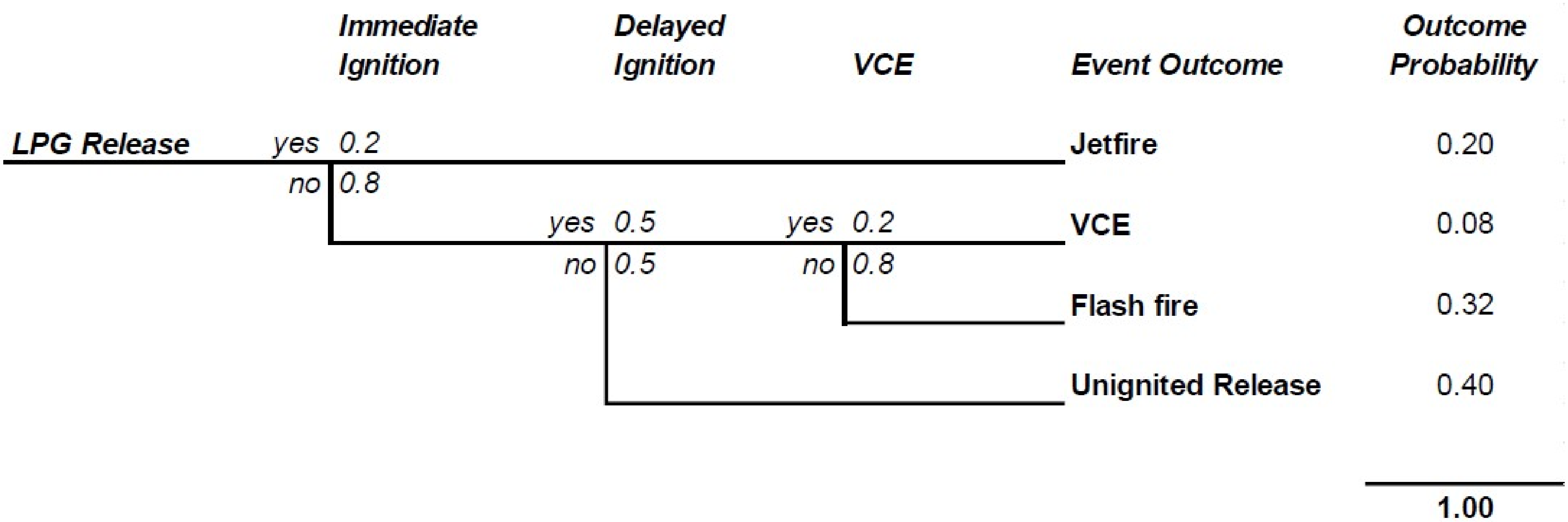

Figure: 6-6	RAMBOLL
Title: Event Tree for Guillotine Failure of Liquid Inlet Pipework and Flexible Hose of the Road Tanker and Submersible Pump Flange	Drawn by: VW Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2 Date: Jan 2025

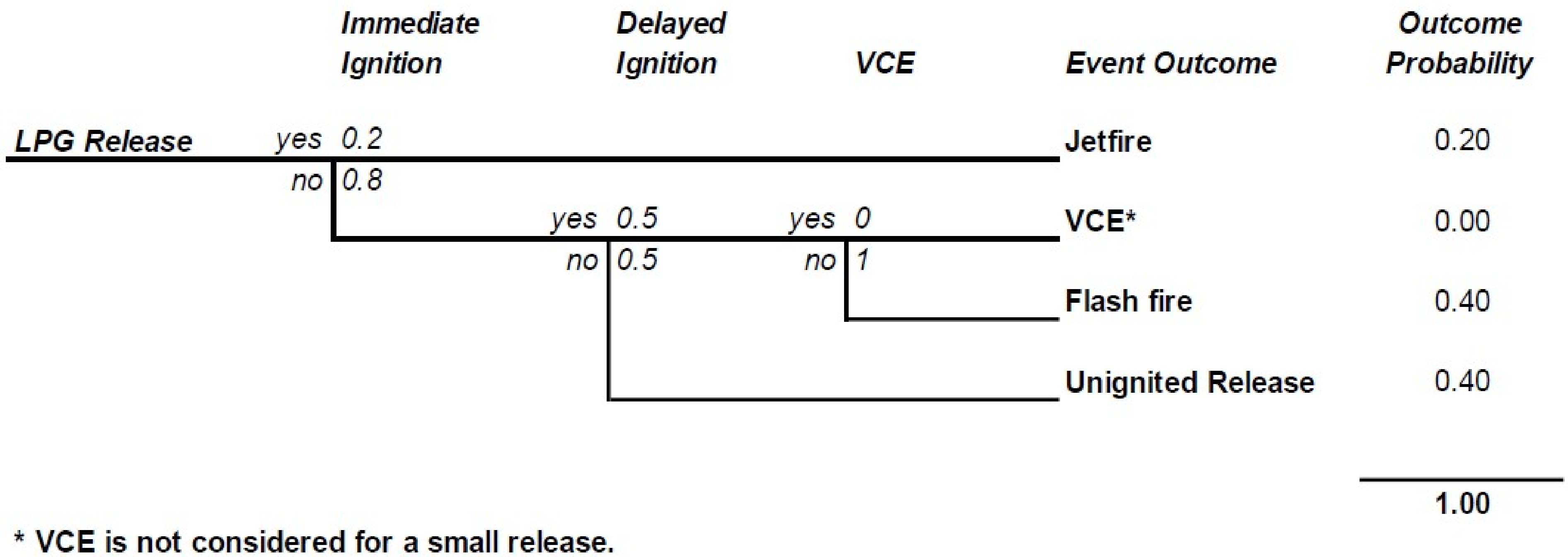

Figure: 6-7	RAMBOLL
Title: Event Tree for Partial Failure of Liquid Inlet Pipework and Flexible Hose of the Road Tanker and Submersible Pump Flange	Drawn by: VW Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2 Date: Jan 2025

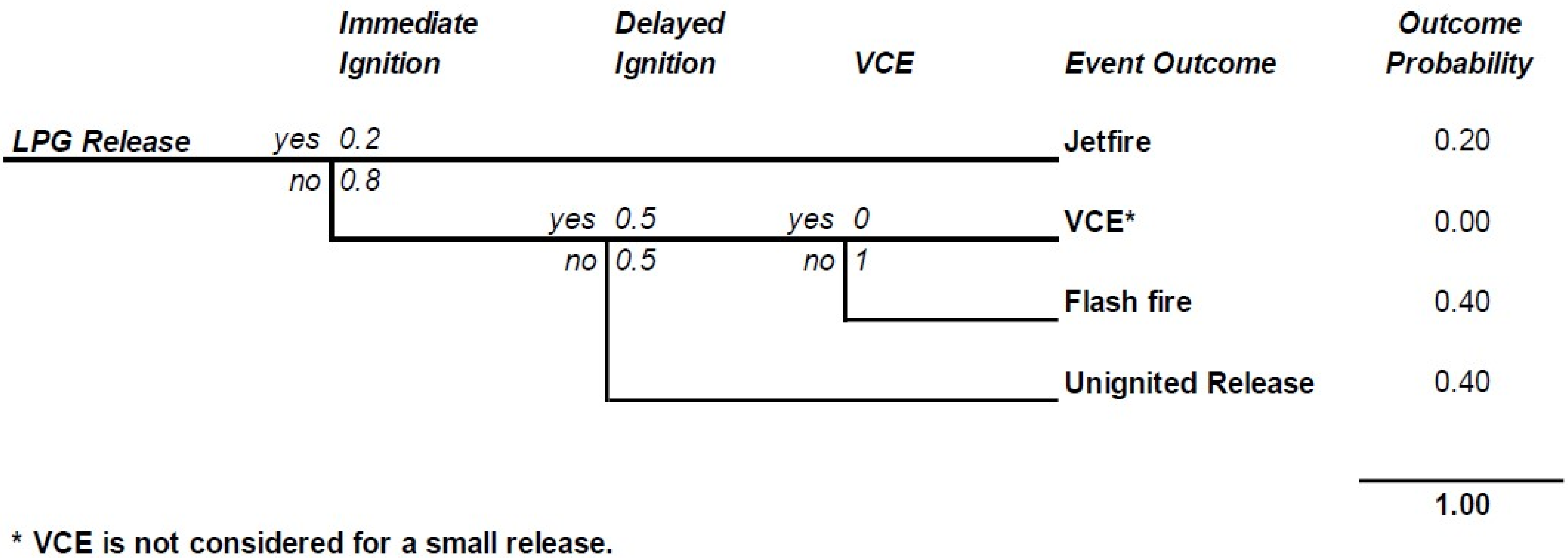

Figure: 6-8	RAMBOLL
Title: Event Tree for Failure of Dispenser and Flexible Hose of the Dispenser	Drawn by: VW
	Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2
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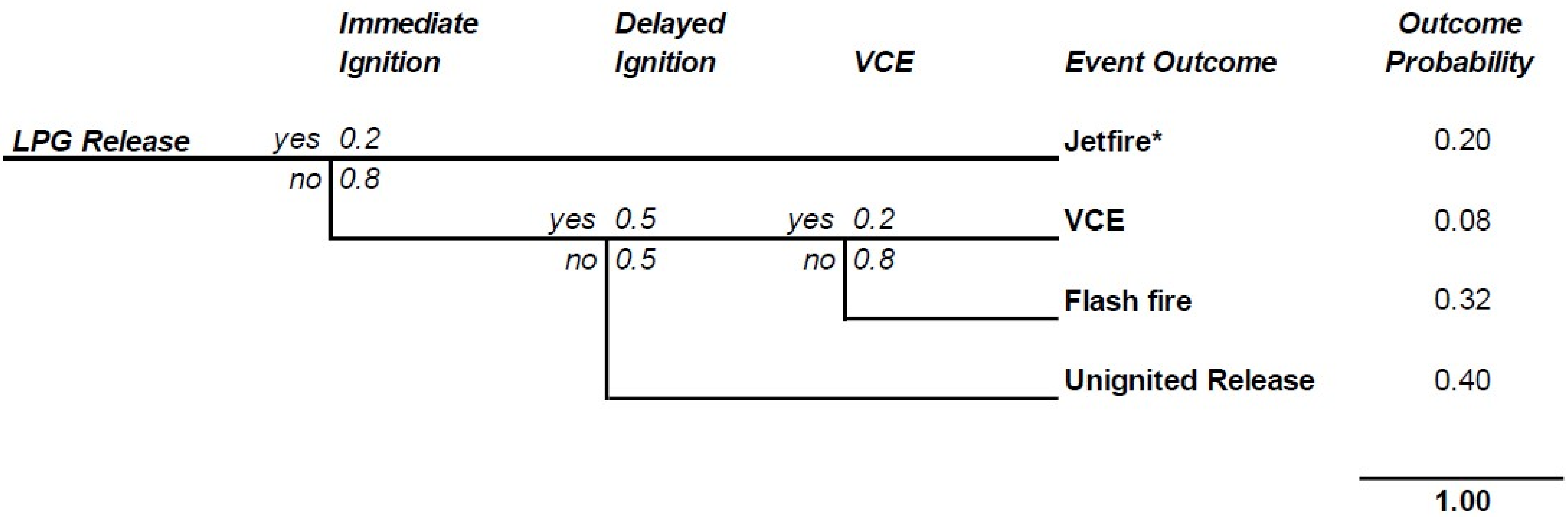

* Vertical Jetfire is considered for failure of the underground pipe.

Figure: 6-9	RAMBOLL
Title: Event Tree for Guillotine Failure of Liquid Supply Line to Dispenser	Drawn by: VW
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Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2
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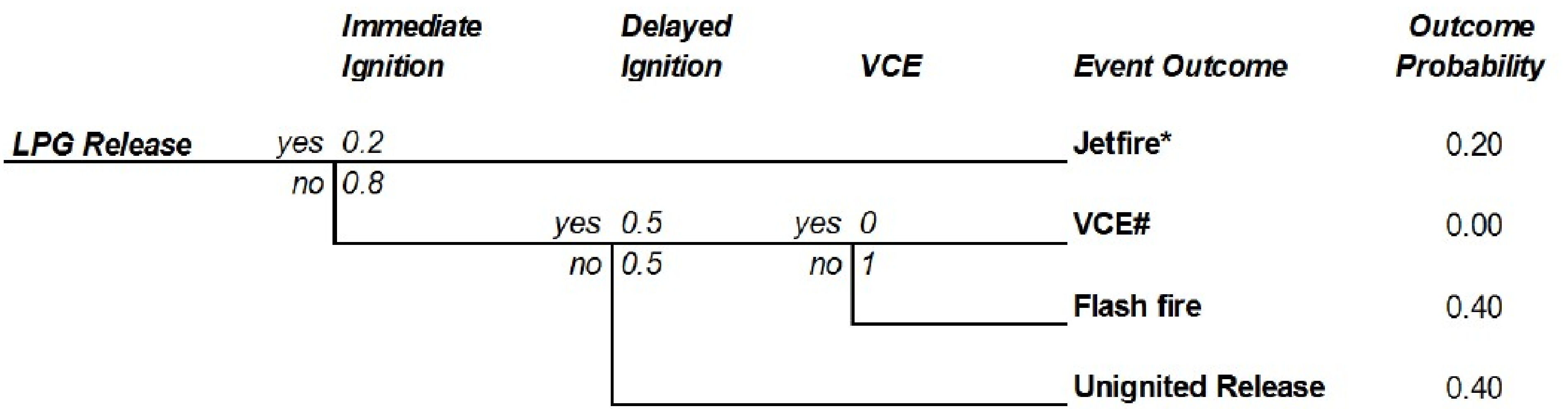

* Vertical Jetfire is considered for failure of the underground pipe.
\# VCE is not considered for a small release.

Figure: 6-10		RAMBOLL
Title: Event Tree for Partial Failure of Liquid Supply Line to Dispenser	Drawn by:	VW
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Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.:	2
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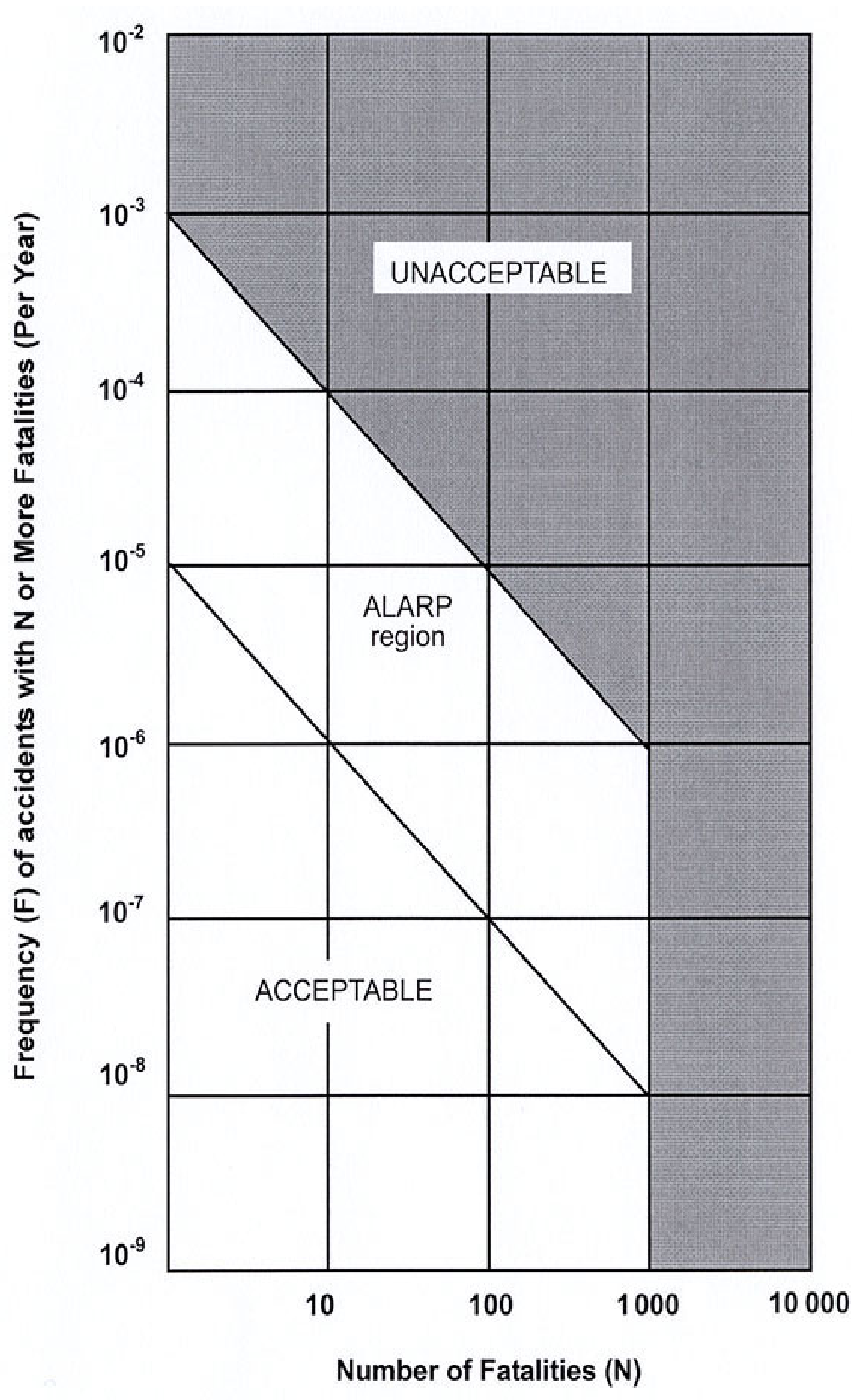

Figure: 8-1	RAMBOLL
Title: F-N Curves in comparison with Hong Kong Risk Guidelines	Drawn by: VW
	Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2
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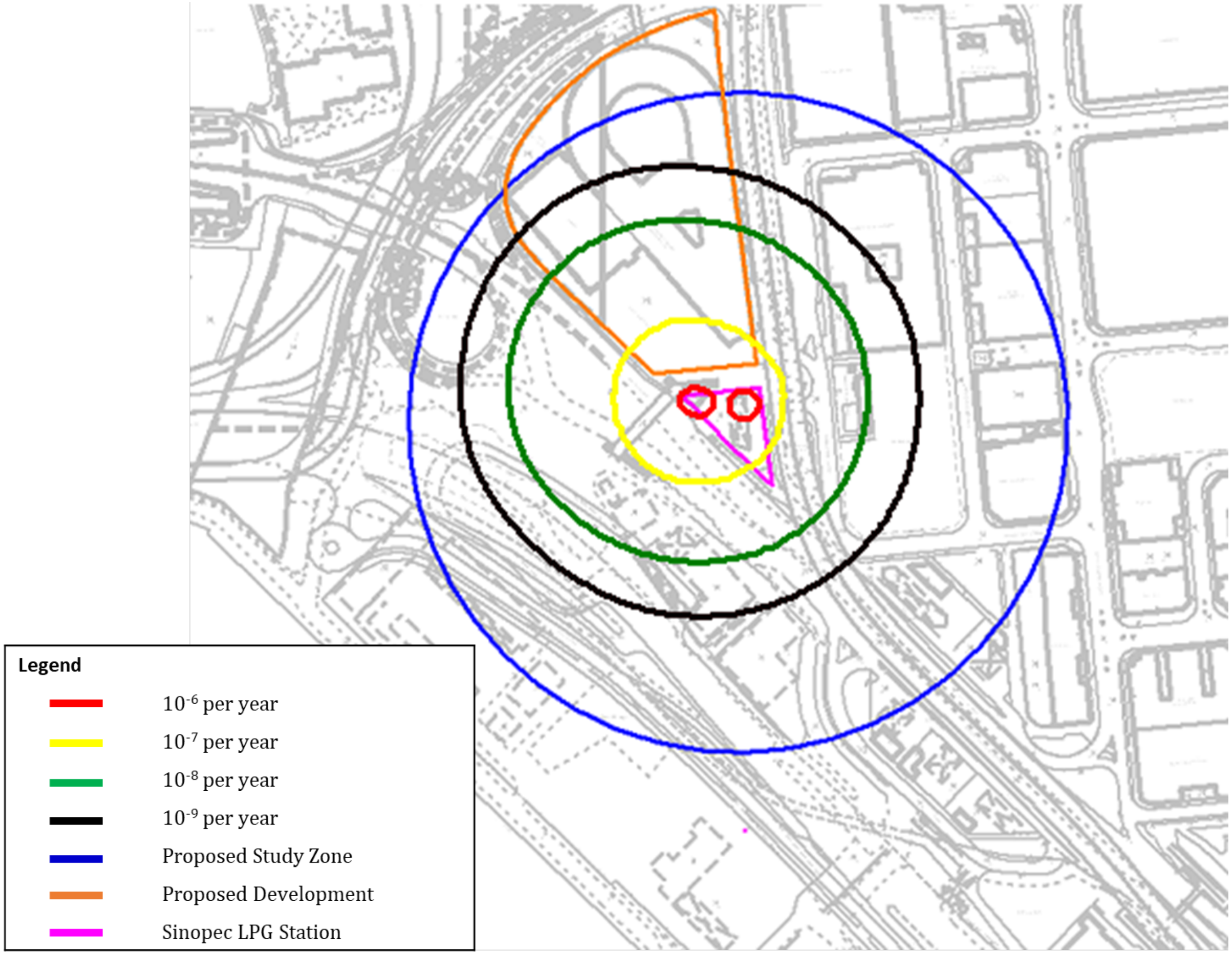

Figure: 8-2	RAMBOLL
Title: Location Specific Individual Risk Contours of the LPG Filling Station (LPG A Sinopec LPG Refueling Station)	Drawn by: VW
	Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2
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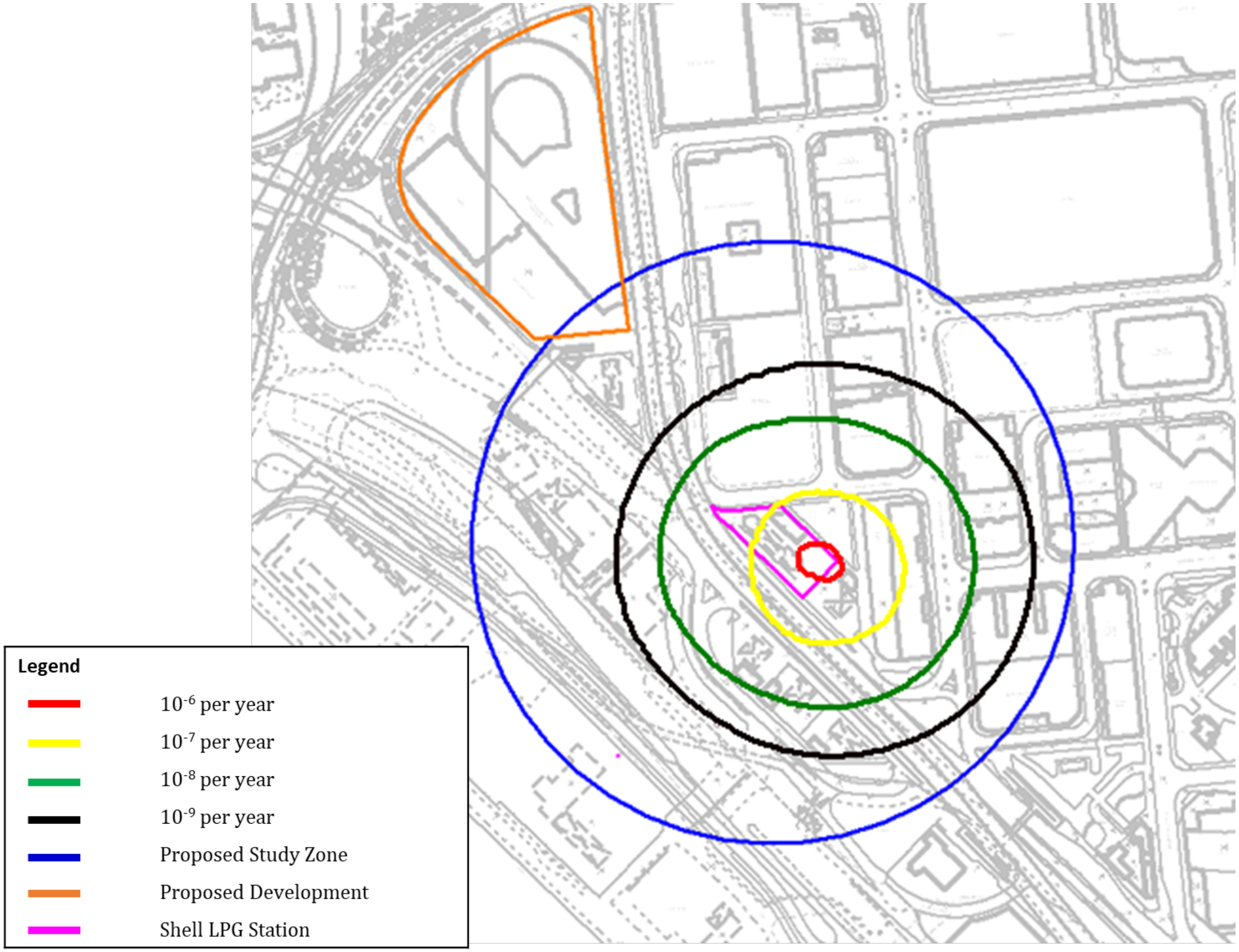


Figure: 8-3	RAMBOLL
Title: Location Specific Individual Risk Contours of the LPG Filling Station (LPG B Shell LPG Refueling Station)	Drawn by: VW Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2 Date: Jan 2025

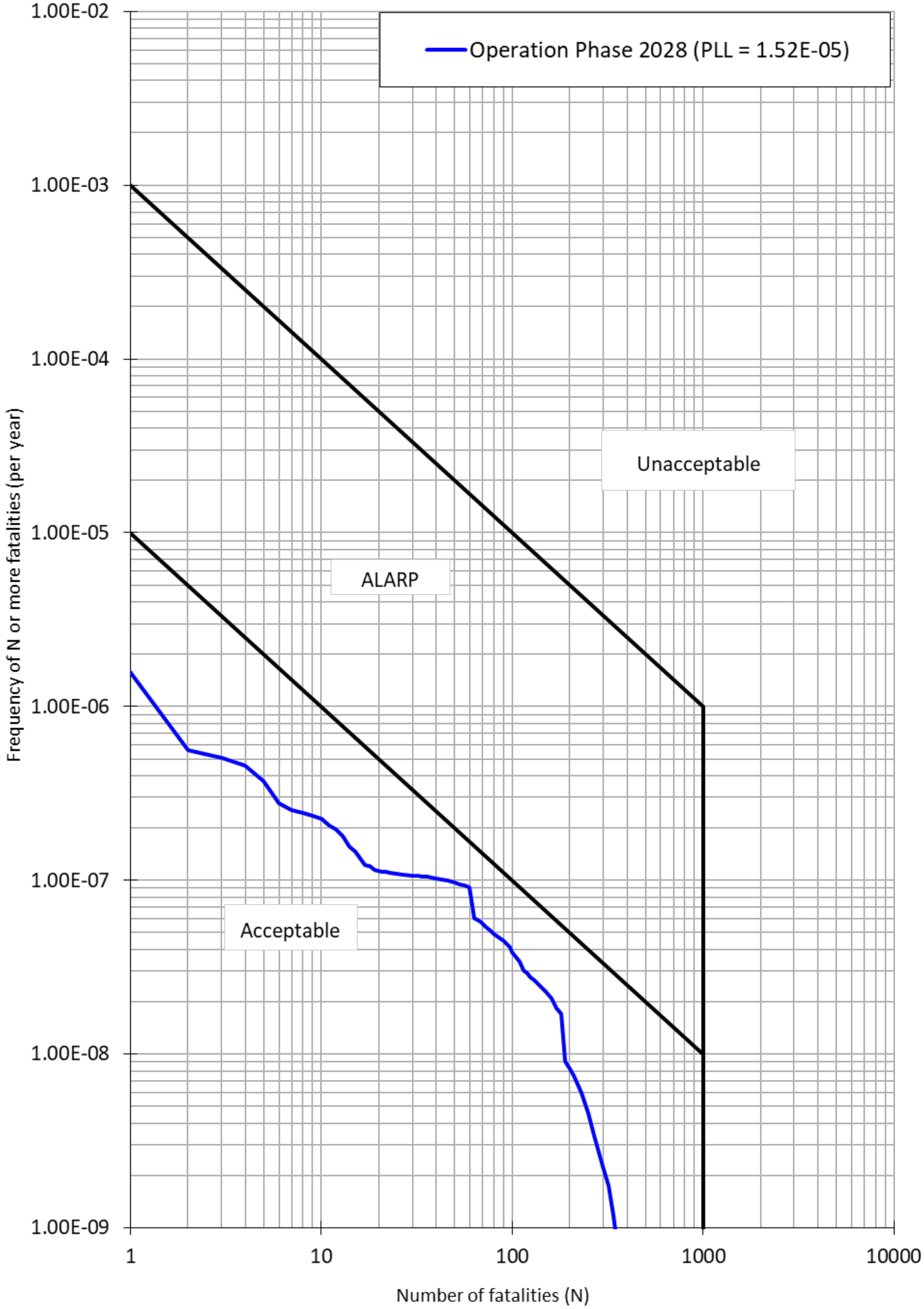


Figure: 8-4	RAMBOLL
Title: F-N Curves in comparison with Hong Kong Risk Guidelines (LPG A Sinopec LPG Refueling Station)	Drawn by: VW Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2 Date: Jan 2025

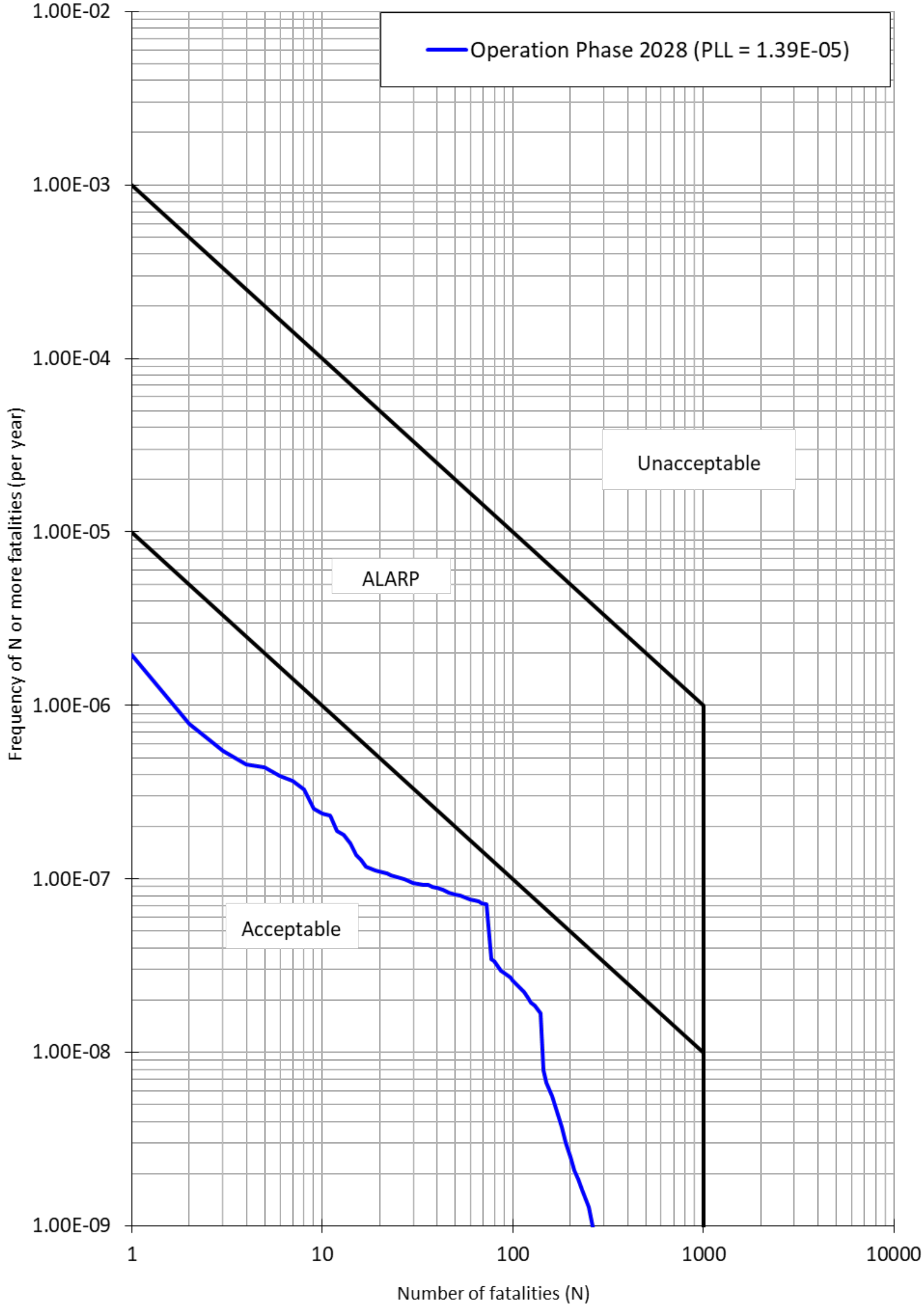


Figure: 8-5	RAMBOLL
Title: F-N Curves in comparison with Hong Kong Risk Guidelines (LPG B Shell LPG Refueling Station)	Drawn by: VW Checked by: SP
Project: Proposed Residential (Flat) and Permitted Commercial and Trade Mart Redevelopment with Minor Relaxation of Building Height Restriction, New Kowloon Inland Lot No. 6032, 1 Trademart Drive, Kowloon Bay, Kowloon	Rev.: 2 Date: Jan 2025

Appendix 4-1

Assumptions for this QRA Study

APPENDIX 4-1 ASSUMPTIONS FOR THIS QRA STUDY

1.1 *SURROUNDING DATA ANALYSIS*

1.1.1 *Meteorological Data*

Assumption Number: 1.1.1

As per Appendix 4.B of "*Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)*", at least six representative weather classes are recommended to be adopted in this QRA Study, covering the stability conditions of stable, neutral and unstable, low and high wind speed. At least the following six (6) weather classes have to be covered in terms of Pasquill classes.

Stability Class	Wind Speed (1)
B	Medium
D	Low
D	Medium
D	High
E	Medium
F	Low

(1): Low wind speed corresponding to 1 – 2 m s^{-1}
Medium wind speed corresponding to 3 – 5 m s^{-1}
High wind speed corresponding to 8 – 9 m s^{-1}

Several rules will be applied to classify the observations in the six weather classes:

1. Observations in the Pasquill stability classes A, A/B, B and B/C are grouped to class B while the wind speed of the weather class is equal to the average wind speed of the observations.

2. Observations in the Pasquill stability classes C, C/D, D are grouped to class D while the wind speed of the weather class is equal to the average wind speed of the observations. Wind speeds below 2.5 m s^{-1}, between 2.5 m s^{-1} and 6 m s^{-1} and above 6 m s^{-1} are classified as the wind speed categories low, medium and high respectively.

3. Observations in the Pasquill stability classes E and F are allocated on the basis of the wind speed. Wind speeds below 2.5 m s^{-1} and above 2.5 m s^{-1} are classified as weather classes F and E respectively. The wind speed in each weather class is equal to the average wind speed of the observations in the weather class.

Assumption Number: 1.1.1

The allocation of six (6) representative weather classes is shown in following figure.

<table>
<tr><th>Wind Speed</th><th>A</th><th>B</th><th>B/C</th><th>C</th><th>C/D</th><th>D</th><th>E</th><th>F</th></tr>
<tr><td>< 2.5 $m\ s^{-1}$</td><td colspan="3" rowspan="3">B medium</td><td colspan="3">D low</td><td colspan="2">F low</td></tr>
<tr><td>2.5 – 6 $m\ s^{-1}$</td><td colspan="3">D medium</td><td colspan="2" rowspan="2">E medium</td></tr>
<tr><td>>6 $m\ s^{-1}$</td><td colspan="3">D high</td></tr>
</table>

Data available can be separated for night-time and daytime, in which case, the period of the day attributed to daytime should have the daytime and night-time statistics added correctly.

The mean temperature of 23.3°C and relative humidity of 78% recorded at the Hong Kong Observatory between years 1981–2010 were used in the modelling.

1.1.2 *Surface Roughness*

Assumption Number: 1.1.2

The roughness parameter reflects the average roughness over which cloud is dispersing. For consequence modelling conducted using *DNV Phast Risk*, a value of 50 cm should be selected representing a conditions of parkland, bushes, and numerous obstacles.

1.2 FREQUENCY ANALYSIS

1.2.1 *Ignition Probability*

Assumption Number: 1.2.1

Source		Ignition Probability
Continuous	**Instantaneous**	
< 10 kg s^{-1}	< 1,000 kg	0.2
10 – 100 kg s^{-1}	1,000 – 10,000 kg	0.5
> 100 kg s^{-1}	> 10,000 kg	0.7

A probability of 0.5 is assigned to delayed ignition, which may produce a flash fire or a VCE. The occurrence of a VCE requires an ignition of a dispersed gas cloud present in a confined or congested space. Given the relatively open nature of the surroundings of the Compound, an explosion probability of 0.2 is assumed in this QRA study.

1.2.2 *Probability of Ignition for Ignition Sources*

Assumption Number: 1.2.2

As per Appendix 4.A of "Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)", the probability of ignition a time interval of one minute for a number of sources is listed as following table:

Source	Probability of Ignition in one minute
1. Point Source	
motor vehicle	0.4
flare	1.0
outdoor furnace	0.9
indoor furnace	0.45
outdoor boiler	0.45
indoor boiler	0.23
ship	0.5
ship transporting flammable materials	0.3
fishing vessel	0.2
pleasure craft	0.1
diesel train	0.4
electric train	0.8
2. Line Source	
transmission line	0.2 per 100 m
road	Note 1
railway	Note 1
3. Area Source	
chemical plant	0.9 per site
oil refinery	0.9 per site
heavy industry	0.7 per site
light industrial warehousing	as for population
4. Population Source	
residential	0.01 per person
employment force	0.01 per person

Note 1:
The ignition probability for a road or railway near the establishment or transport route under consideration is determined by the average traffic density. The average traffic density, d, is calculated as:

$d = NE/v$

where:

N: number of vehicles per hour (hr^{-1})

E: length of a road or railway selection (km)

v: average velocity of vehicle ($km\ hr^{-1}$)

1.3 *CONSEQUENCE ANALYSIS*

1.3.1 *Source Term Modelling*

Assumption Number: 1.3.1

Most leak sources are at ground level or near ground level. Taking into account release source, 0 m and 1 m is considered a representative height for modelling underground facilities and aboveground facilities in this QRA study.

The averaging time considered for dispersion modelling is 18.75 seconds.

1.3.2 *Fireball and BLEVE Effect*

Assumption Number: 1.3.2

With regard to fireball, a 100% fatality is assumed for any person outdoors within the fireball radius.

1.3.3 *Thermal Radiation of Fires*

Assumption Number: 1.3.3

The following Probit equation is used to determine lethal doses for various fire scenarios:

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

where

Pr Probit corresponding to the probability of death (-)

Q heat radiation ($W\ m^{-2}$)

t exposure time (s)

The exposure time, *t*, is limited to maximum of twenty (20) seconds.

1.3.4 *Flash Fire Effect*

Assumption Number: 1.3.4

With regard to flash fires, a 100% fatality is assumed for any person outdoors within the flash fire envelope. The extent of the flash fire is considered to be the distance to 100% of LFL.

1.3.5 Protection Factor

Assumption Number: 1.3.5

Protection factors are used to factor down the population so that only those exposed to hazardous scenarios are considered in the risk summation.

Protection for indoor population against thermal radiation and flash fire is considered by assuming that the indoor fatality rate is 10% of the outdoor fatality rate.

For persons within the fireball radius/ criteria zone, it was assumed that 50% of person would be killed and 50% indoor protection factor is applied in this QRA study.

2 *REFERENCE*

Drainage Services Department, Harbour Area Treatment Scheme Stage 2A Environmental Impact Assessment, 2008.

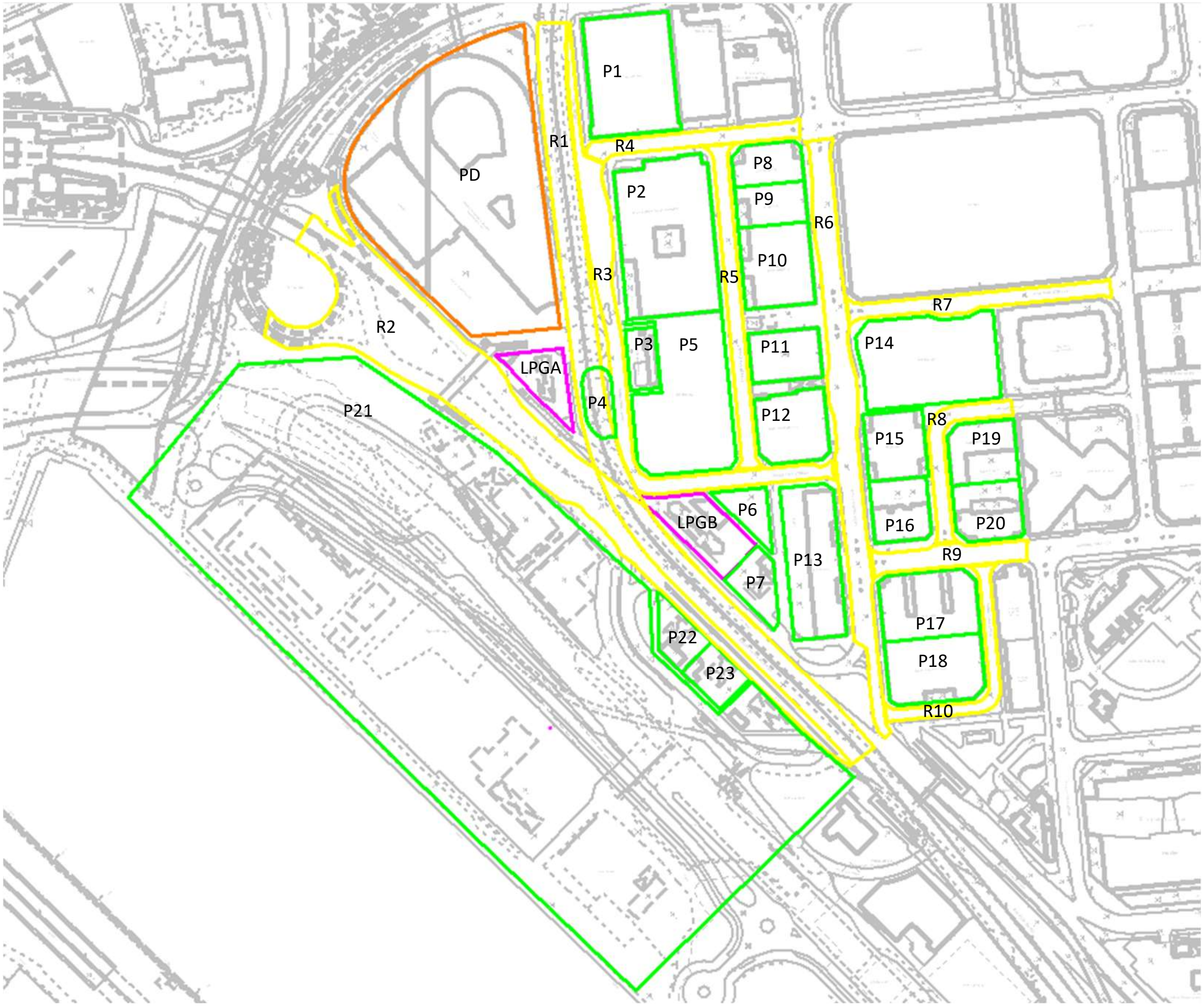
A.B. Reeves, F.C. Minah, V.H.K. Chow, Quantitative Risk Assessment Methodology for LPG Installations, Conference on Risk & Safety Management in the Gas Industry, EMSD&HKIE, Hong Kong, 1997.

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

Appendix 4-2

Off-site Population within Proposed Study Zone and Population Map

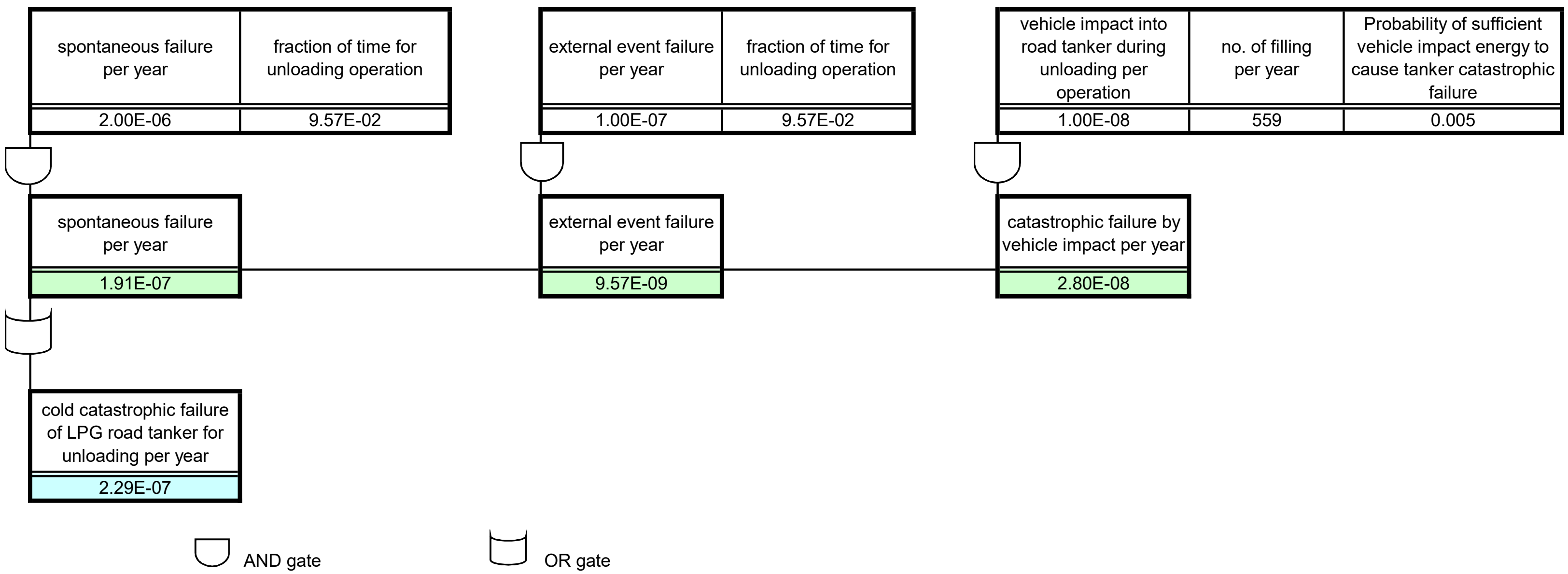
Ref	Name	2023 Base Case	2028 Operational Phase	Weekday Day	Weekend Day	Night	Fraction Indoors	No of Storeys	Remarks
LPGA	Sinopec LPG Station	18	18	15%	15%	1%	0%	1	It is based on the generic population assumption
LPGB	Shell LPG Station #1	18	18	15%	15%	1%	0%	1	It is based on the generic population assumption
P01	HSBC Building Kowloon Bay	200	200	100%	100%	10%	95%	5	It is based on the generic population assumption
P02	Hong Kong Post - Central Mail Centre	400	400	100%	100%	10%	95%	6	It is based on the generic population assumption
P03	Wang Chin Street Substation	0	0	100%	10%	10%	0%	1	It is based on the generic population assumption
P04	Carpark (under Kwun Tong Bypass)	4	4	70%	70%	10%	0%	0	It is based on the generic population assumption
P05	Business Building	1,274	1,274	100%	100%	10%	95%	10	It is based on EIA Study "Agreement No. CE 35/2006 (CE) Kai Tak Development Engineering Study cum Design and Construction of Advance Works – Investigation, Design and Construction"
P06	Construction Site 1 (Project: 0559744)	28	28	100%	100%	10%	20%	2	It is based on the information provided by client
P07	ESSO LPG Station #1	18	18	15%	15%	1%	0%	1	It is based on the generic population assumption
P08	Wing On Godown Building	288	288	100%	10%	10%	95%	7	It is based on the generic population assumption
P09	Camlux Hotel	370	370	50%	80%	90%	95%	7	It is based on the generic population assumption
P10	Jing Hin Industrial Building	288	288	100%	10%	10%	95%	5	It is based on the generic population assumption
P11	Legan Centre	200	200	100%	100%	10%	95%	6	It is based on the generic population assumption
P12	Kinetic Industrial Centre	288	288	100%	10%	10%	95%	7	It is based on the generic population assumption
P13	Billion Centre	400	400	100%	100%	10%	95%	35	It is based on the generic population assumption
P14	Lam Wah Street Playground	50	50	70%	100%	0%	0%	0	It is based on the generic population assumption
P15	Megacube	200	200	100%	100%	10%	95%	8	It is based on the generic population assumption
P16	YHC Tower	400	400	100%	100%	10%	95%	36	It is based on the generic population assumption
P17	Hong Leong Industrial Complex	288	288	100%	10%	10%	95%	8	It is based on the generic population assumption
P18	Kai Fuk Industrial Centre	288	288	100%	10%	10%	95%	7	It is based on the generic population assumption
P19	Corporation Square	400	400	100%	100%	10%	95%	16	It is based on the generic population assumption
P20	Enterprise Square Two	400	400	100%	100%	10%	95%	26	It is based on the generic population assumption
P21	Planned Commercial use	100	16,000	100%	100%	10%	95%	10	Derived based on worker density in Section 8, Ch5 of the HKPSG, plot ratio (5.8/8.0) and site areas (37,954m2/ 13,471m2) based on comments from Planning Department
P22	ESSO LPG Station #2	18	18	15%	15%	1%	0%	1	It is based on the generic population assumption
P23	Shell LPG Station #2	18	18	15%	15%	1%	0%	1	It is based on the generic population assumption
PD	Proposed Development	7,649	9,616	50%	80%	100%	95%	36	2023 base case population refers to the approved S.16 (A/K22/34); 2028 population provided by client
R01	Kwun Tong Bypass	97	101	100%	100%	20%	0%	0	It is based on site visit and ATC2022. No pedestrain was assumed along R01 (Kwun Tong Bypass). The parameters for traffic population are listed below: AADT: 69540; Distance: 0.59 km; Speed: 80 km/hr; and average occupancy: 2.7 people/vehicle
R02	Kai Fuk Road	207	216	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 20 pedestrain was assumed along R02 (Kai Fuk Road). The parameters for traffic population are listed below: AADT: 68320; Distance: 0.73 km; Speed: 50 km/hr; and average occupancy: 2.7 people/vehicle
R03	Trademart Drive	21	21	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 20 pedestrain was assumed along R03 (Trademart Drive). The parameters for traffic population are listed below: AADT: 367.6; Distance: 0.47 km; Speed: 50 km/hr; and average occupancy: 2.7 people/vehicle
R04	Wang Chin Street	22	22	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 20 pedestrain was assumed along R04 (Wang Chin Street). The parameters for traffic population are listed below: AADT: 1838; Distance: 0.15 km; Speed: 50 km/hr; and average occupancy: 2.7 people/vehicle
R05	Wang Kee Street	22	22	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 20 pedestrain was assumed along R05 (Wang Kee Street). The parameters for traffic population are listed below: AADT: 1838; Distance: 0.23 km; Speed: 50 km/hr; and average occupancy: 2.7 people/vehicle
R06	Wang Kwong Street	35	36	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 20 pedestrain was assumed along R06 (Wang Kwong Street). The parameters for traffic population are listed below: AADT: 9190; Distance: 0.42 km; Speed: 50 km/hr; and average occupancy: 2.7 people/vehicle
R07	Lam Wah Street	22	22	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 20 pedestrain was assumed along R07 (Lam Wah Street). The parameters for traffic population are listed below: AADT: 1838; Distance: 0.19 km; Speed: 50 km/hr; and average occupancy: 2.7 people/vehicle
R08	Lam Lok Street	21	22	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 20 pedestrain was assumed along R08 (Lam Lok Street). The parameters for traffic population are listed below: AADT: 1838; Distance: 0.14 km; Speed: 50 km/hr; and average occupancy: 2.7 people/vehicle
R09	Sheung Yuet Road	21	21	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 20 pedestrain was assumed along R09 (Sheung Yuet Road). The parameters for traffic population are listed below: AADT: 1838; Distance: 0.11 km; Speed: 50 km/hr; and average occupancy: 2.7 people/vehicle
R10	Wang Tung Street	22	22	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 20 pedestrain was assumed along R10 (Wang Tung Street). The parameters for traffic population are listed below: AADT: 1838; Distance: 0.17 km; Speed: 50 km/hr; and average occupancy: 2.7 people/vehicle



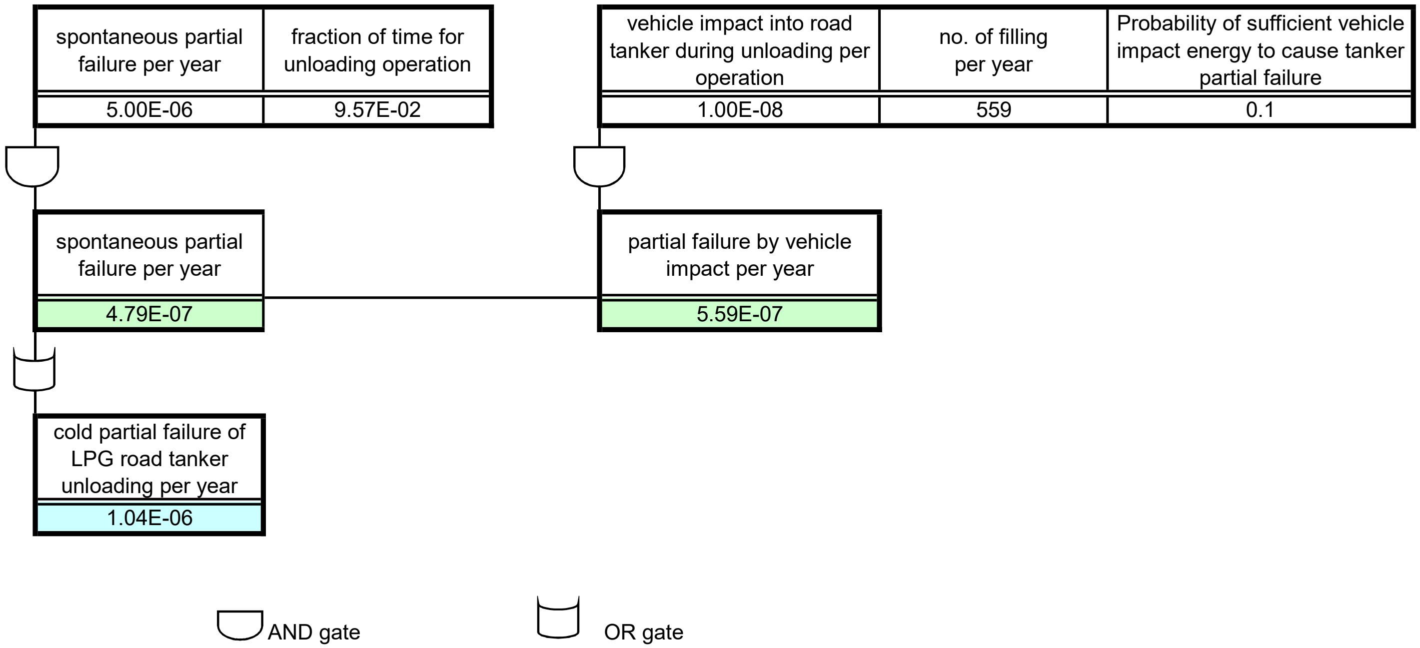
P1
R1
R4
PD
P8
P2
P9
R6
P10
R3
R5
R7
R2
P3
P5
P11
P14
LPGA
P4
P12
P21
R8
P15
P19
LPGB
P6
P16
P20
R9
P13
P7
P17
P22
P18
P23
R10

Appendix 6-1

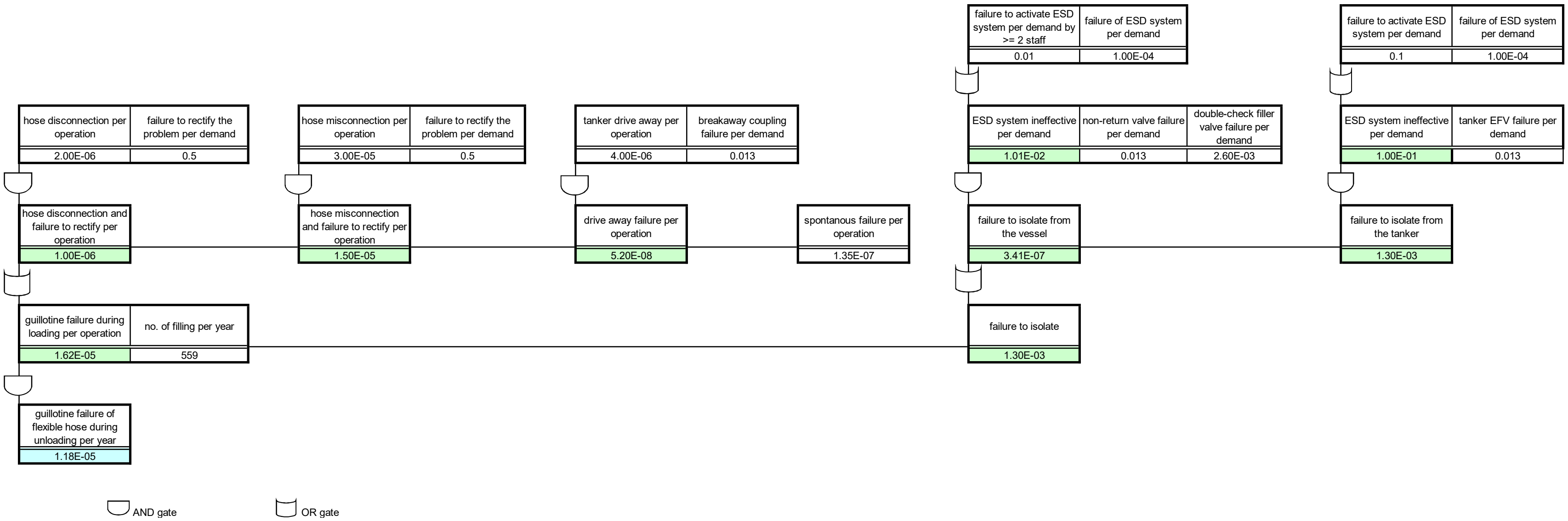
Fault Tree Analysis (LPG A Sinopec Filling Station)



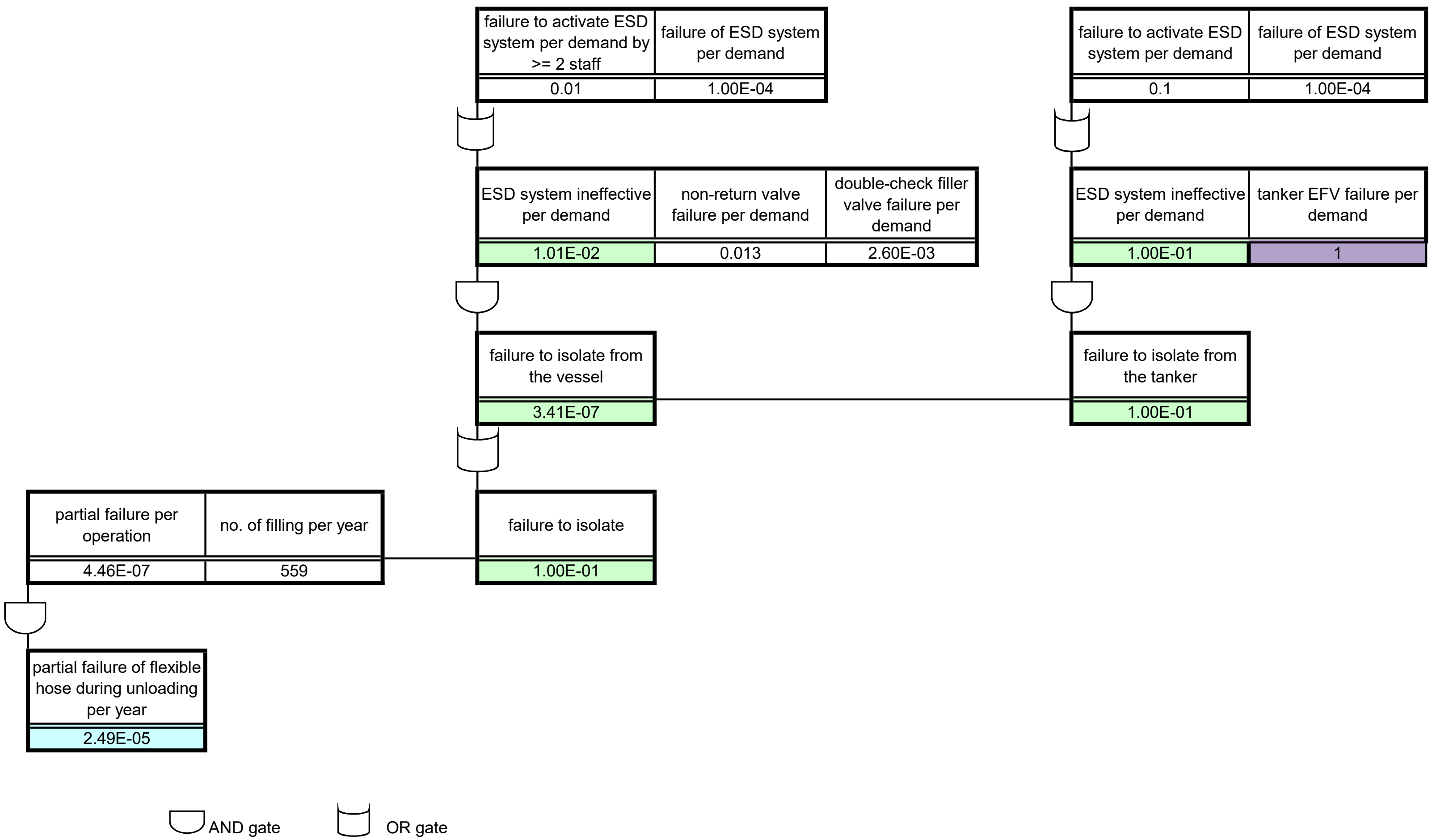
Cold Catastrophic failure of Road Tanker (LPG Filling Station)



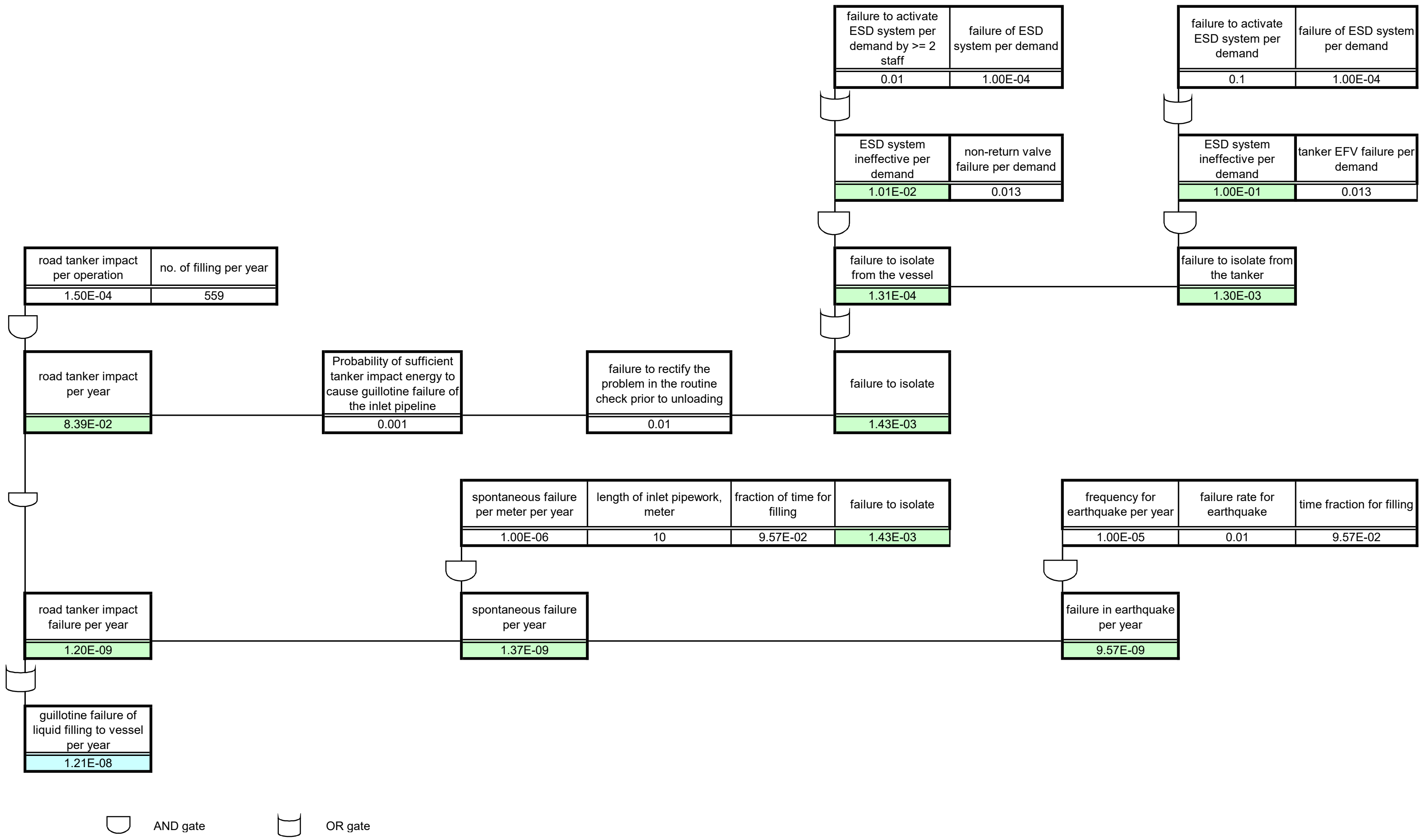
Partial failure of Road Tanker (LPG Filling Station)



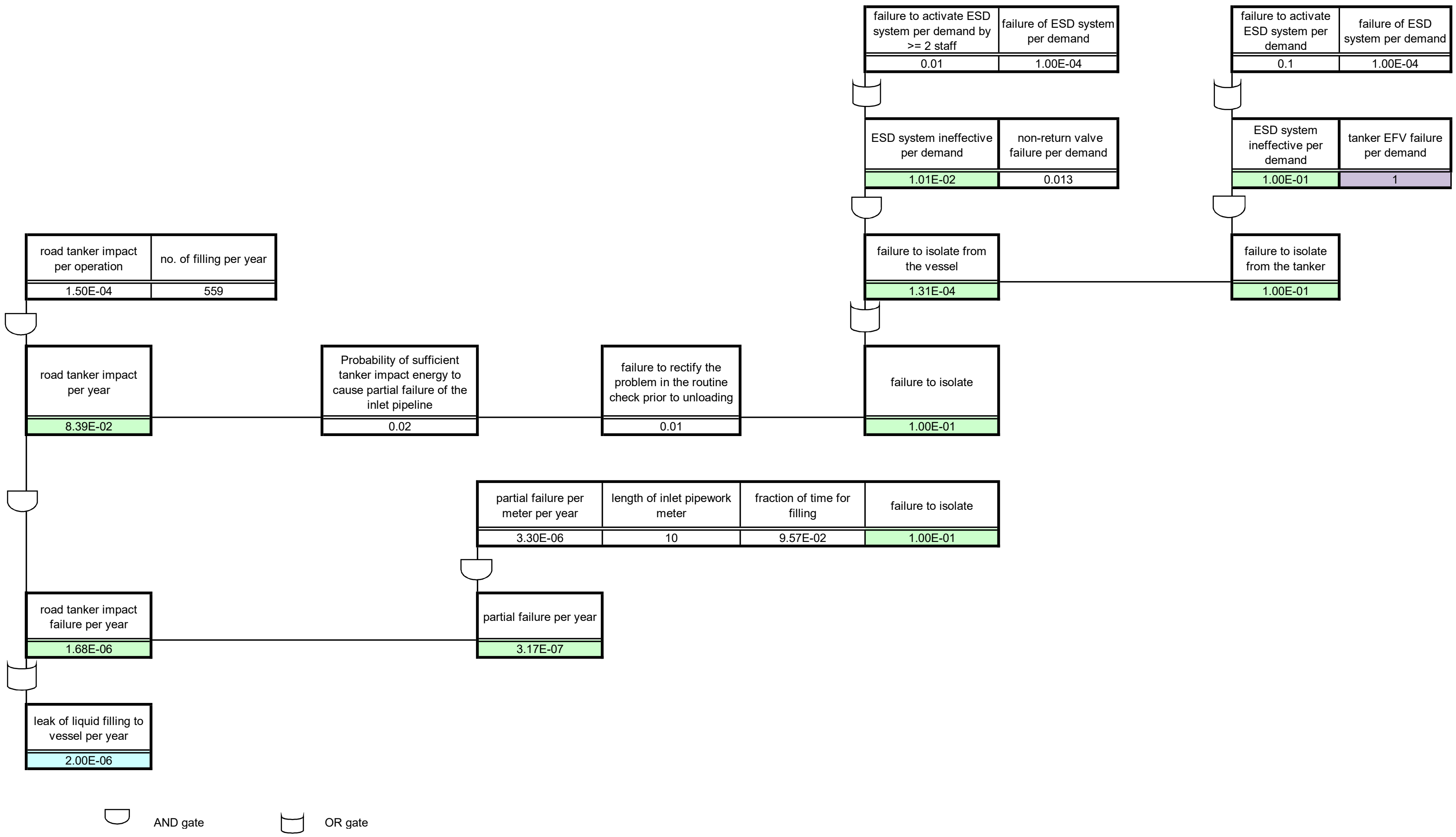
Guillotine failure of Flexible Hose during Unloading to the LPG vessel (LPG Filling Station)



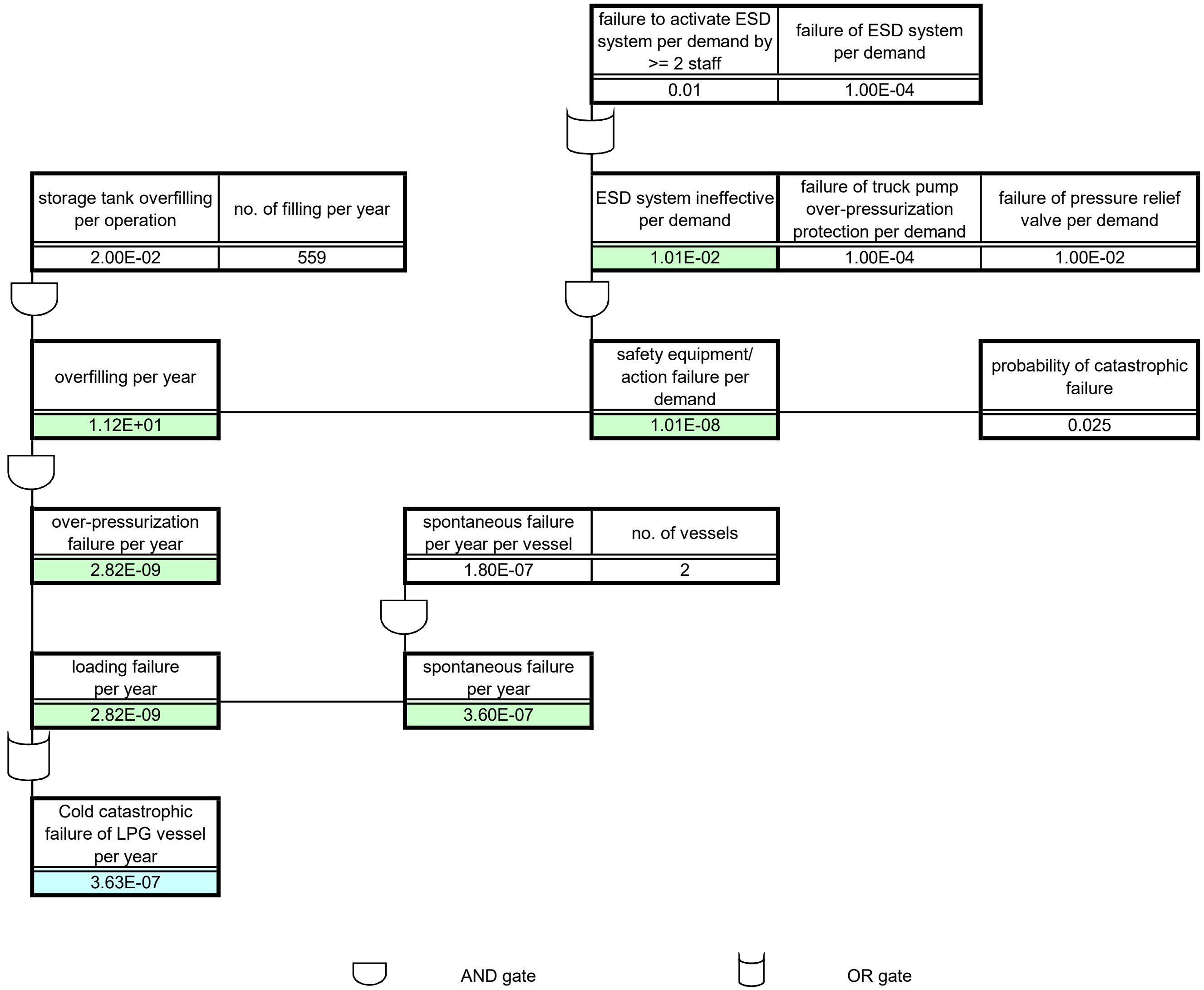
Partial failure of Flexible Hose during Unloading to the LPG vessel (LPG Filling Station)



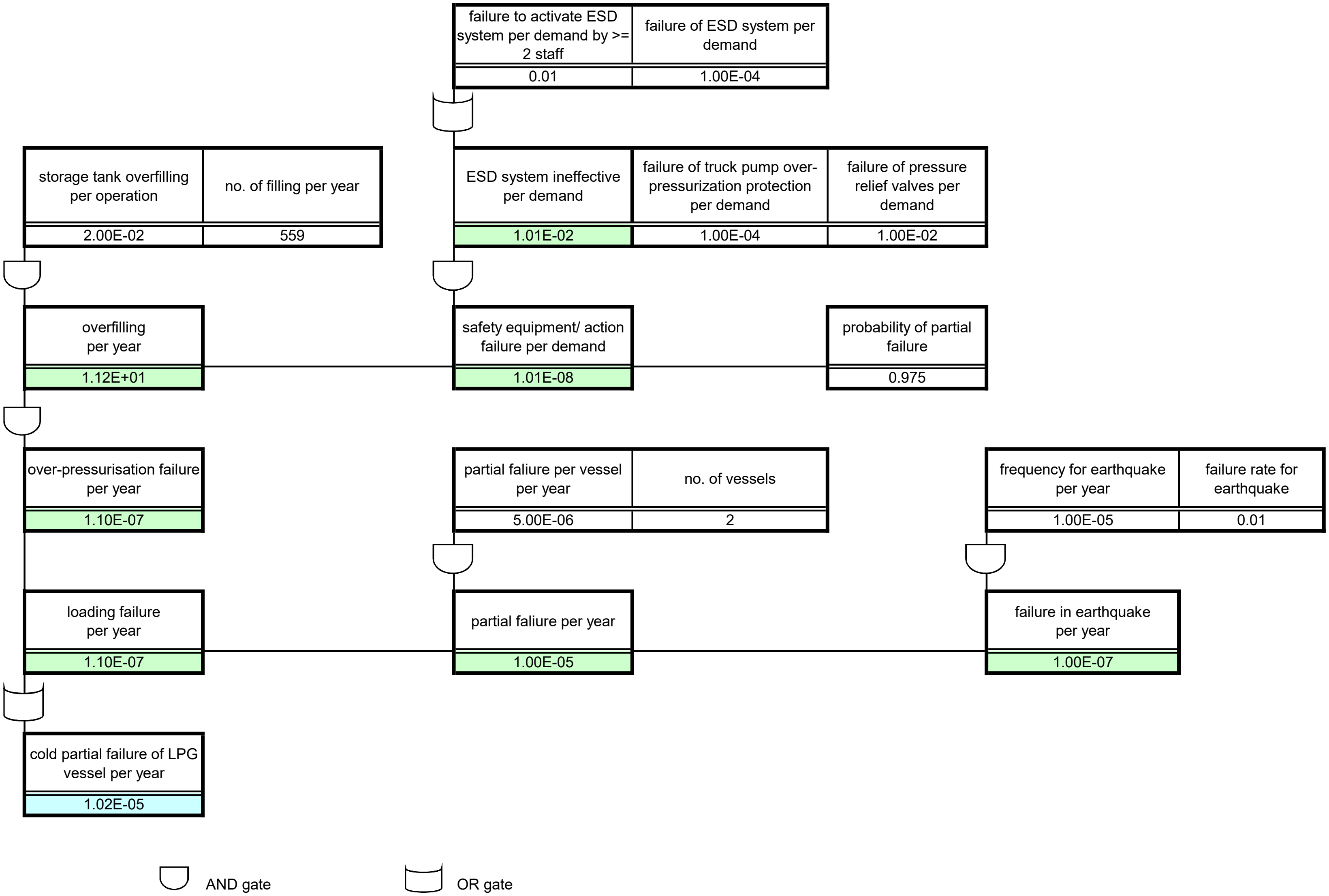
Guillotine failure of Inlet Pipeline (LPG Filling Station)



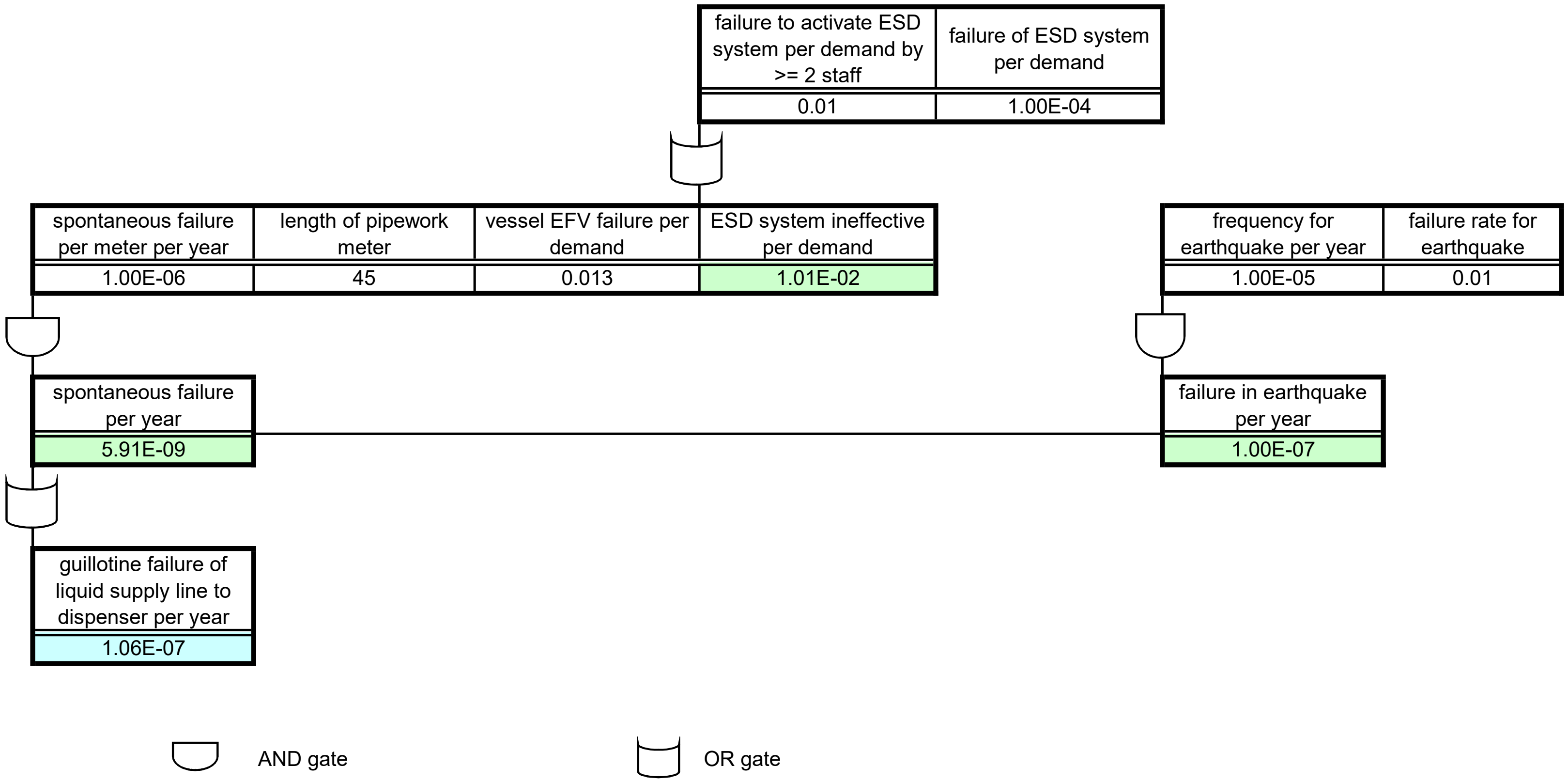
Partial failure of Inlet Pipeline (LPG Filling Station)



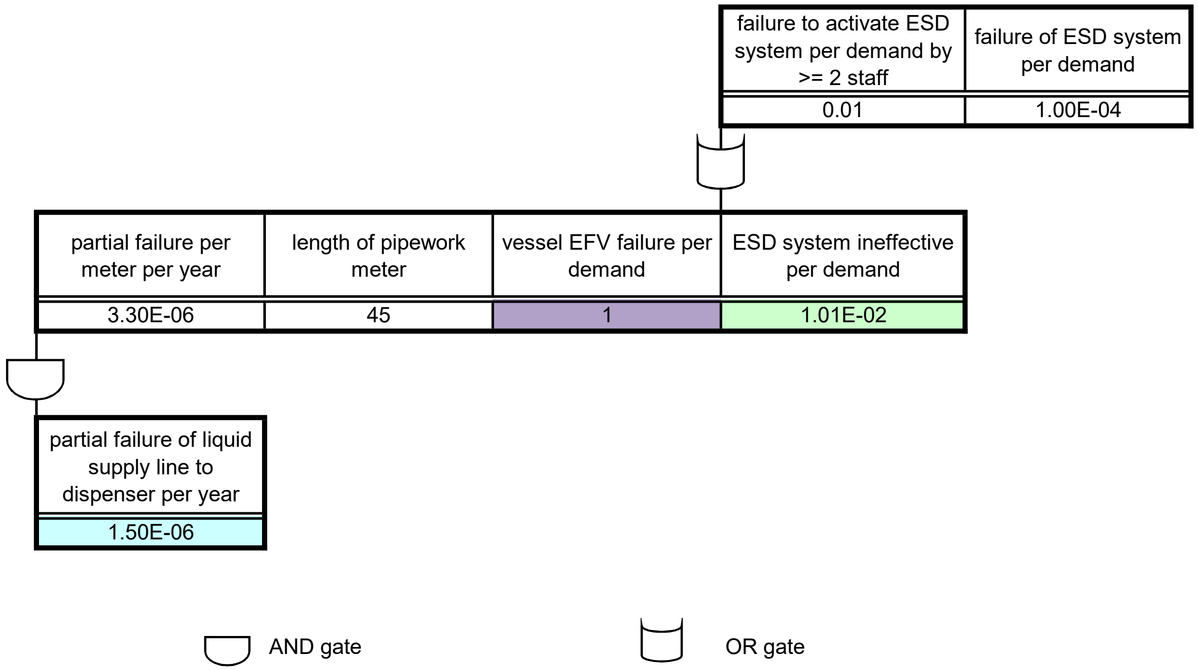
Cold Catastrophic Failure of LPG Vessel (LPG Filling Station)



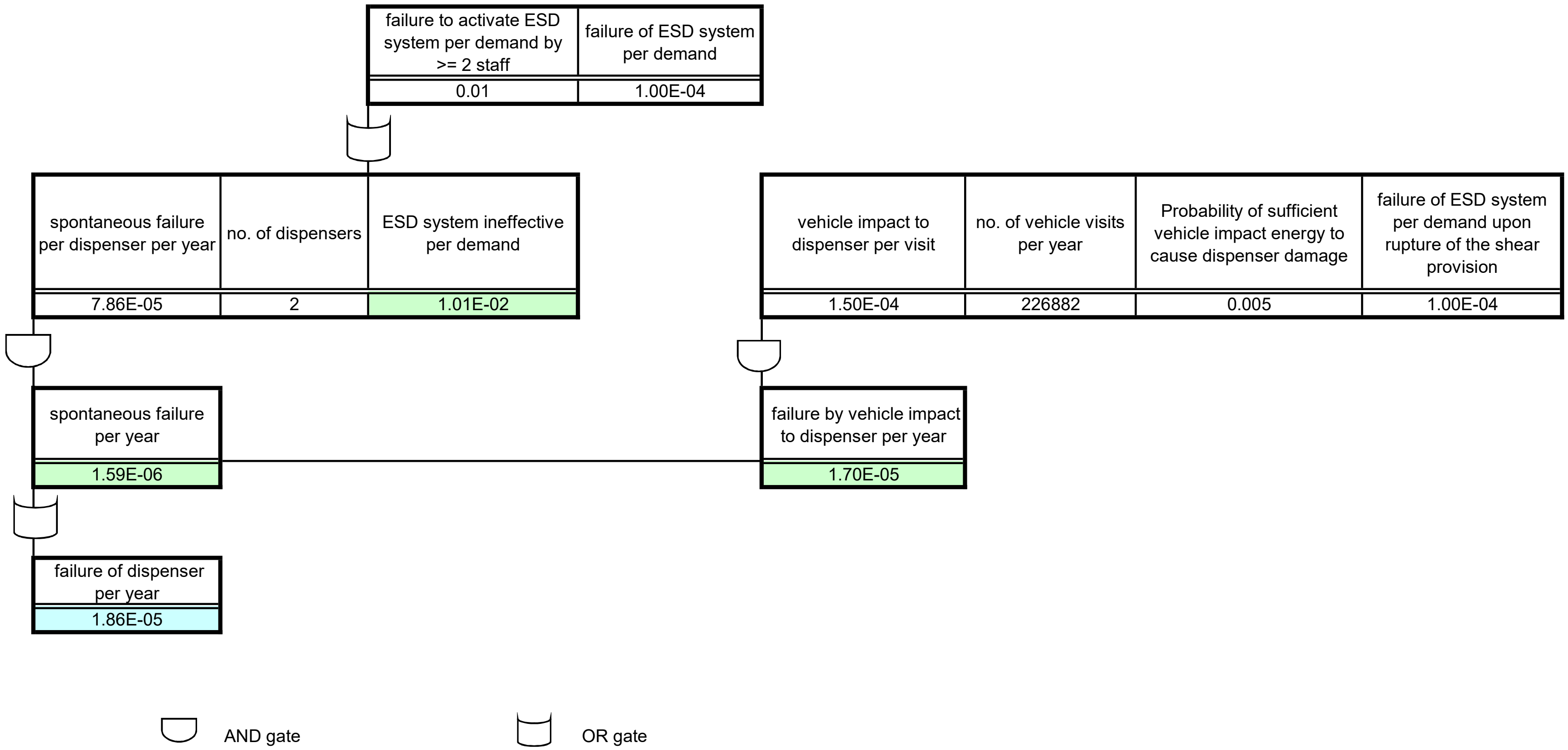
Partial Failure of LPG Vessel (LPG Filling Station)



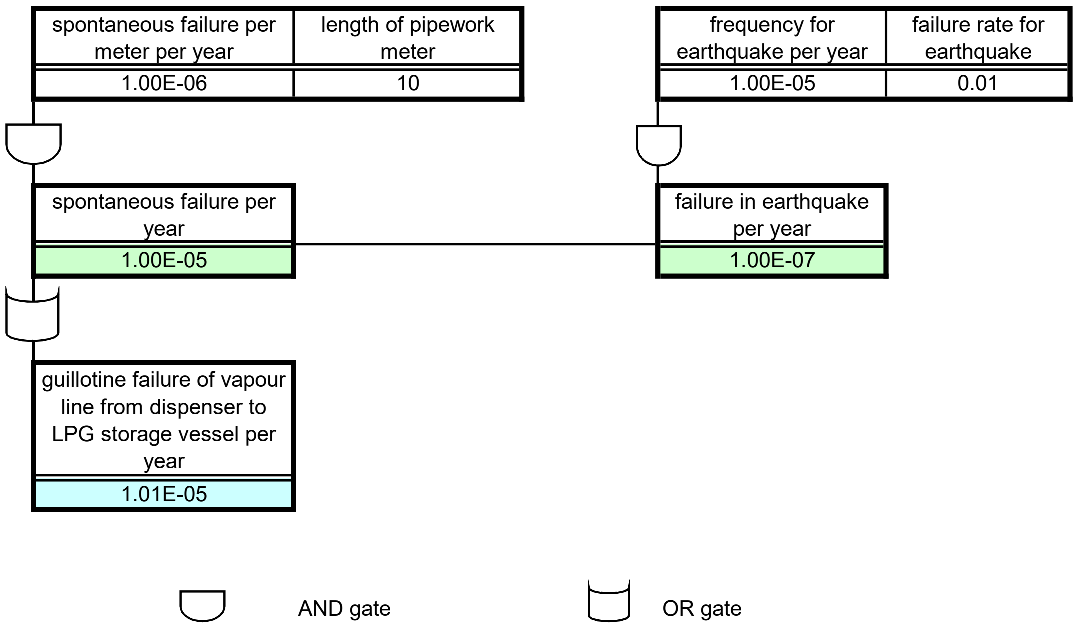
Guillotine failure of the Liquid Supply Pipeline to the Dispenser (LPG Filling Station)



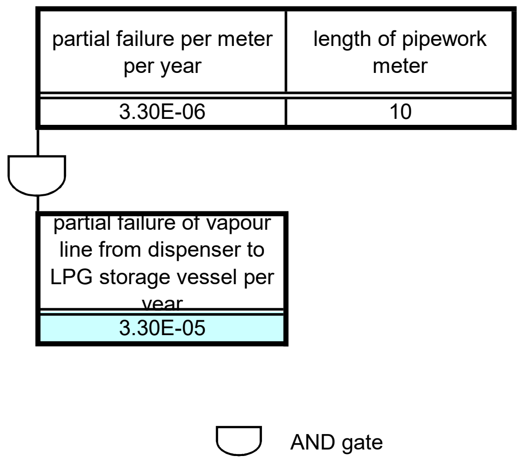
Partial failure of the Liquid Supply Pipeline to the Dispenser (LPG Filling Station)



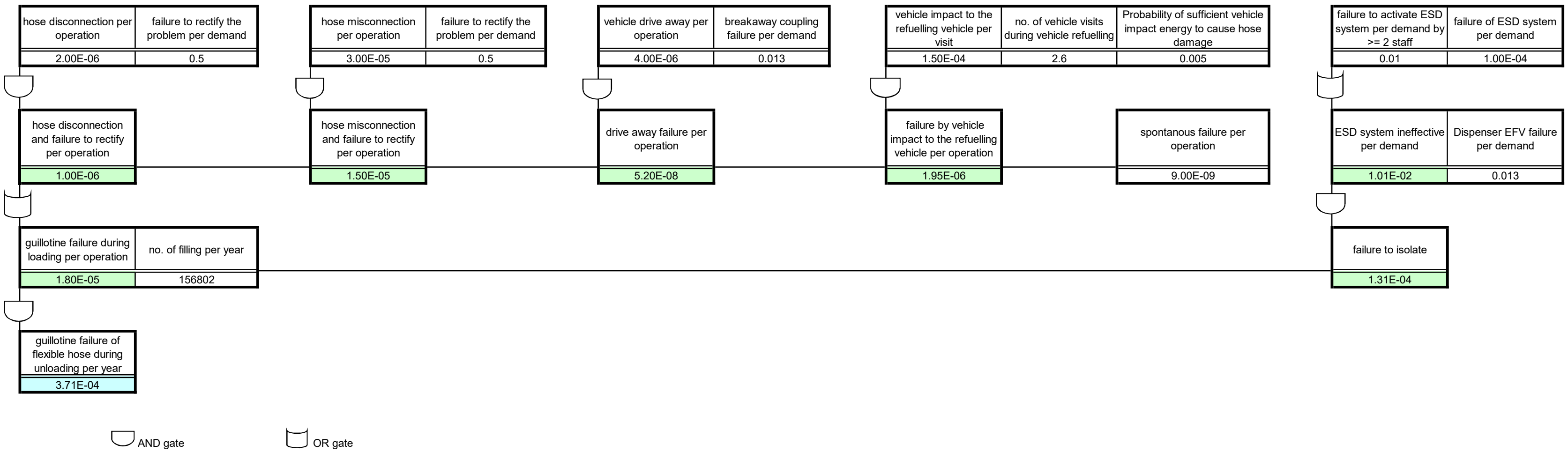
Failure of the Dispenser (LPG Filling Station)



Guillotine failure of Vapour Line from Dispensers to LPG Storage Vessel



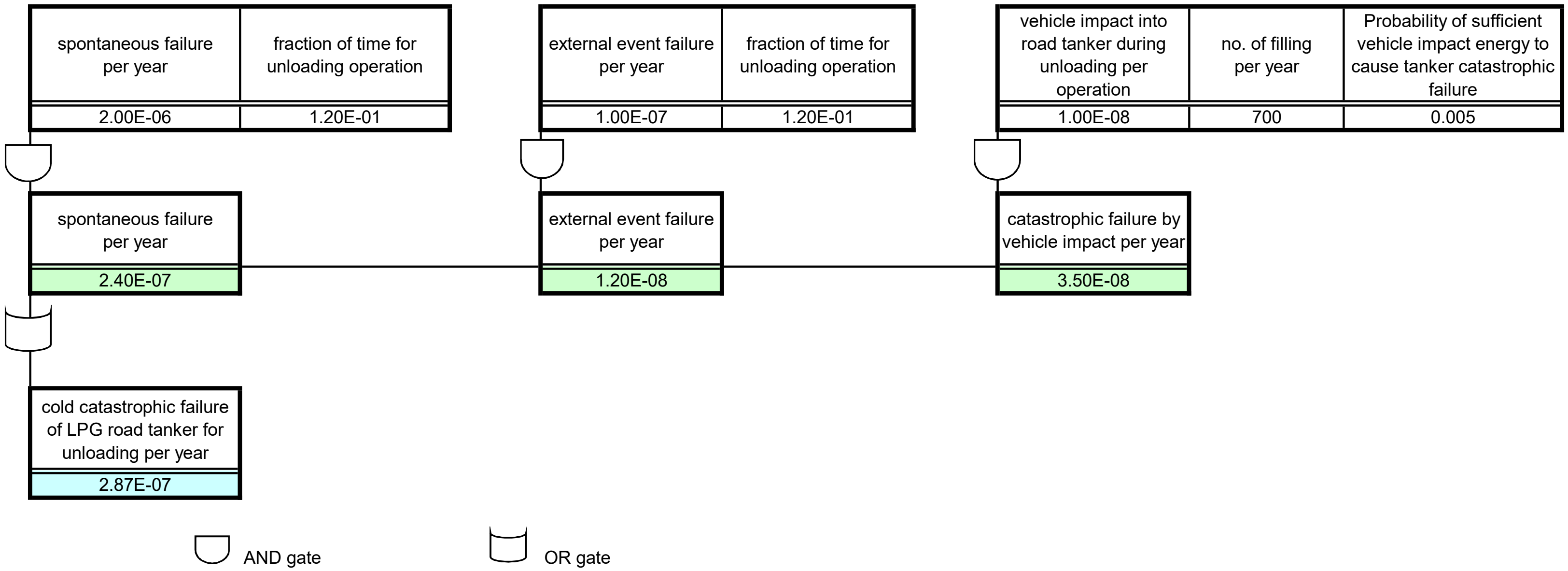
Partial failure of Vapour Line from Dispensers to LPG Storage Vessel



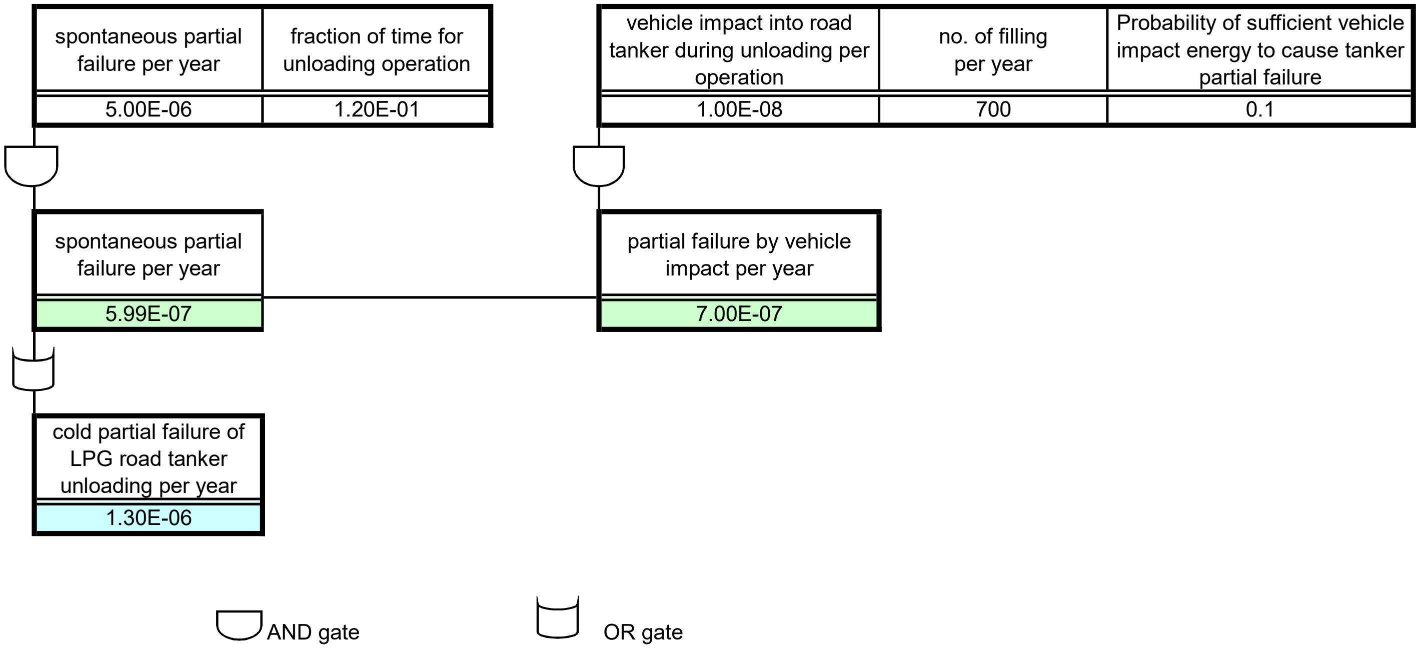
Guillotine failure of Flexible Hose during Filling to the LPG Vehicle (LPG Filling Station)

Appendix 6-2

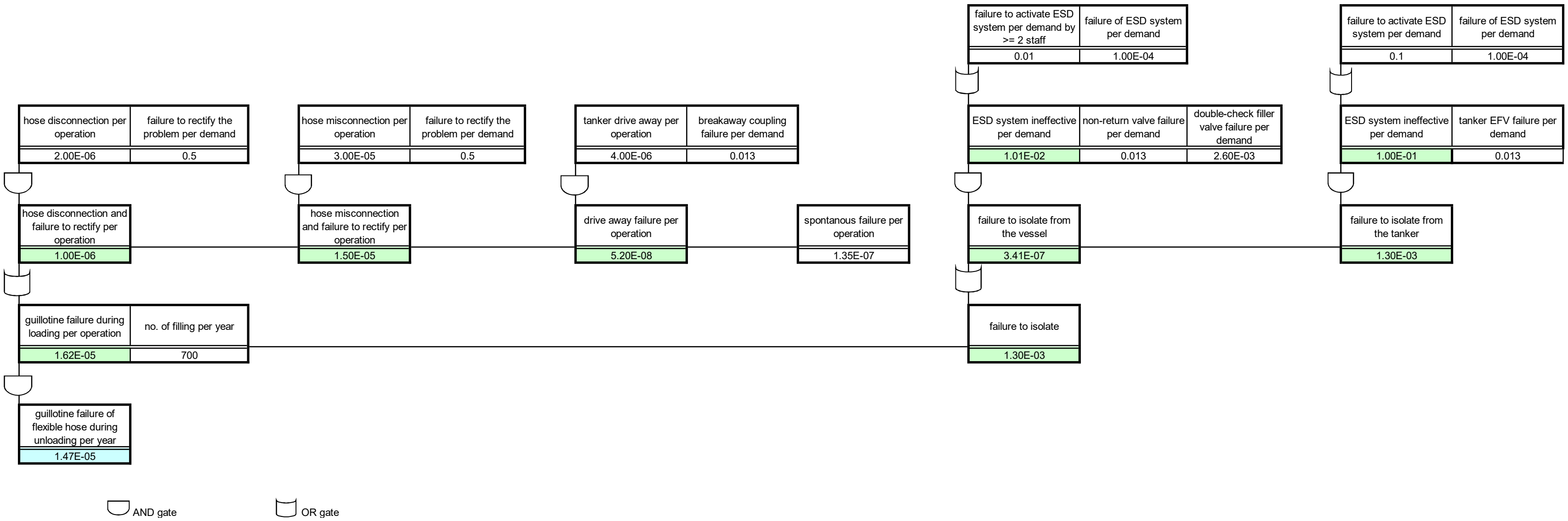
Fault Tree Analysis (LPG B Shell Filling Station)



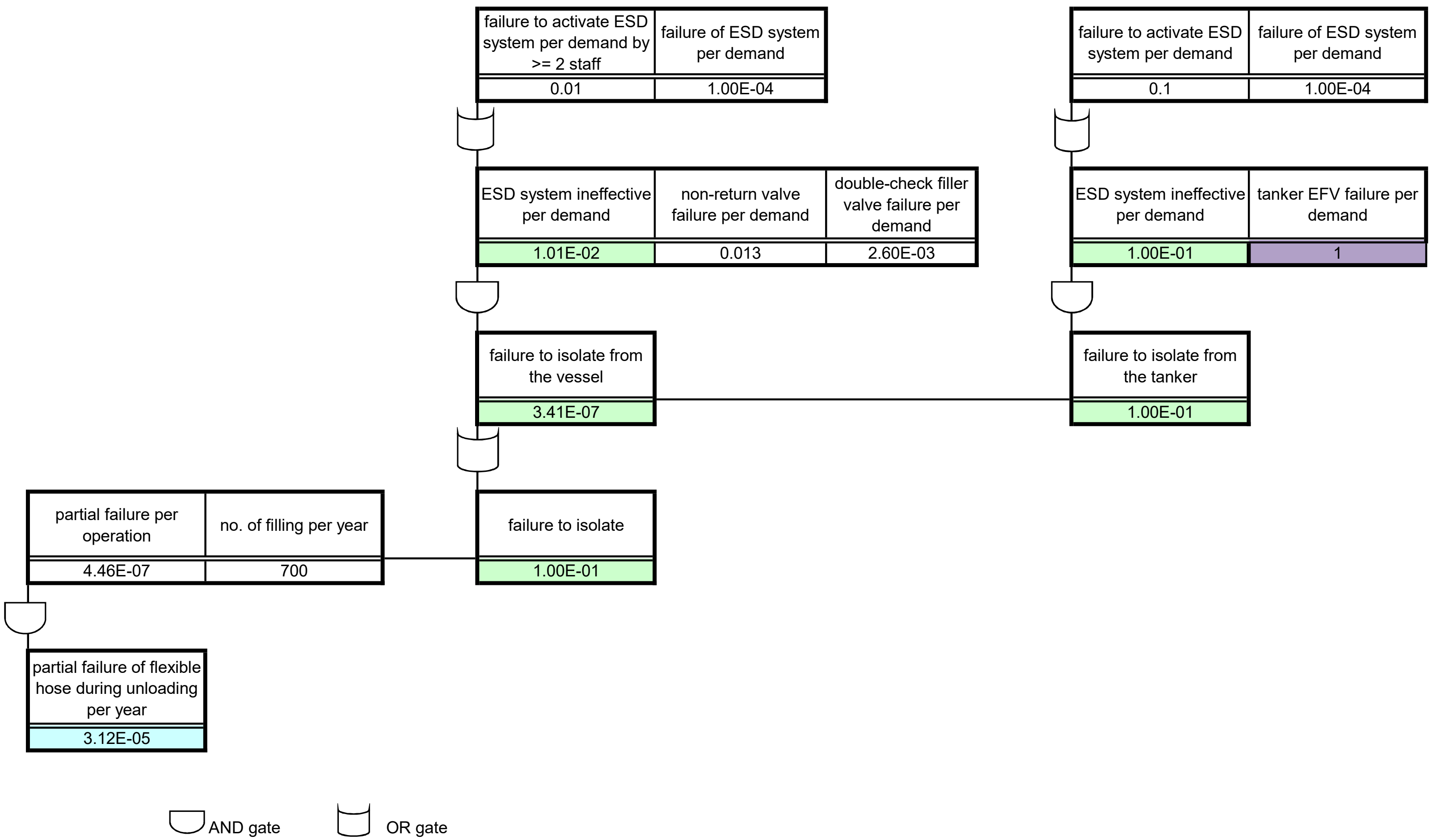
Cold Catastrophic failure of Road Tanker (LPG Filling Station)



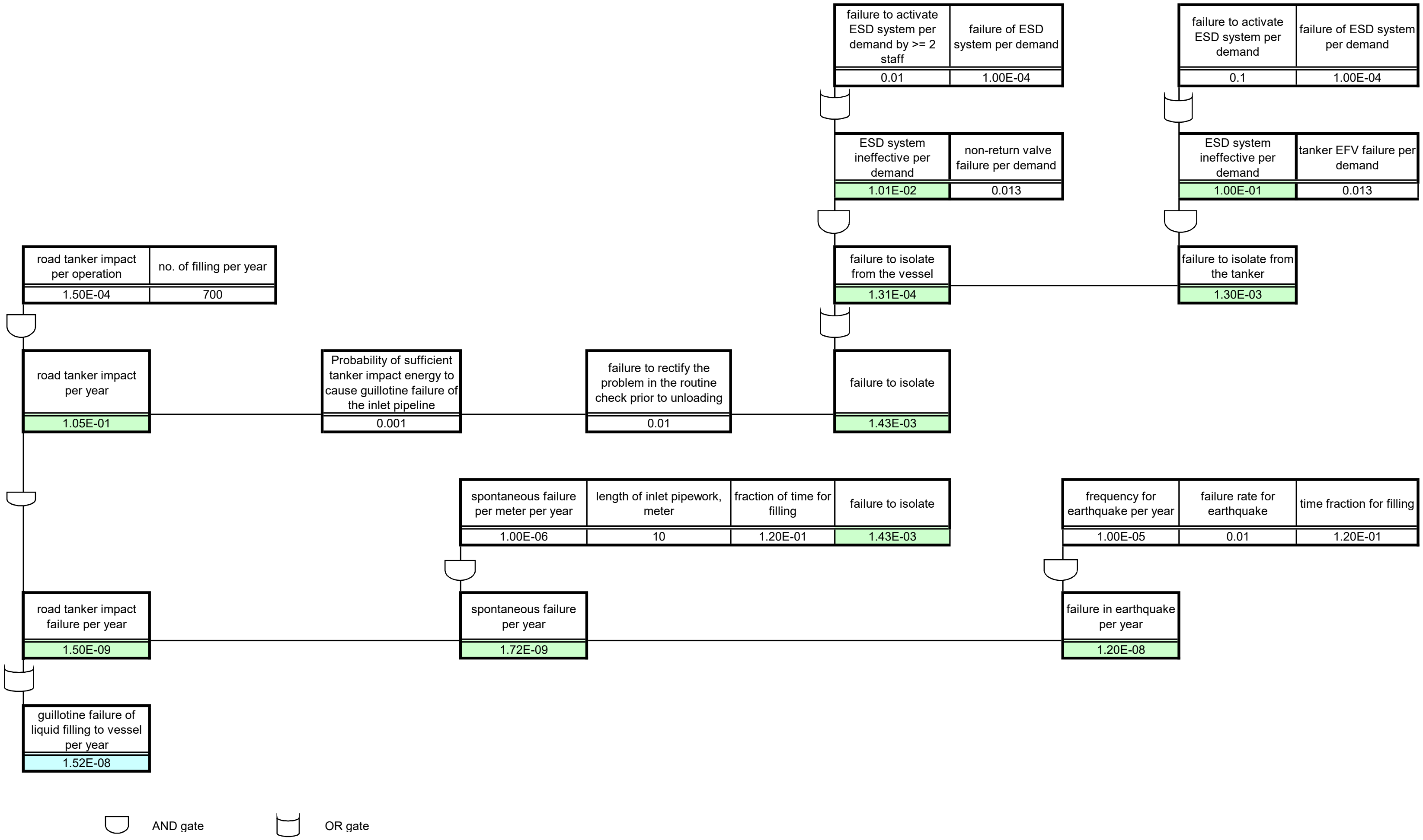
Partial failure of Road Tanker (LPG Filling Station)



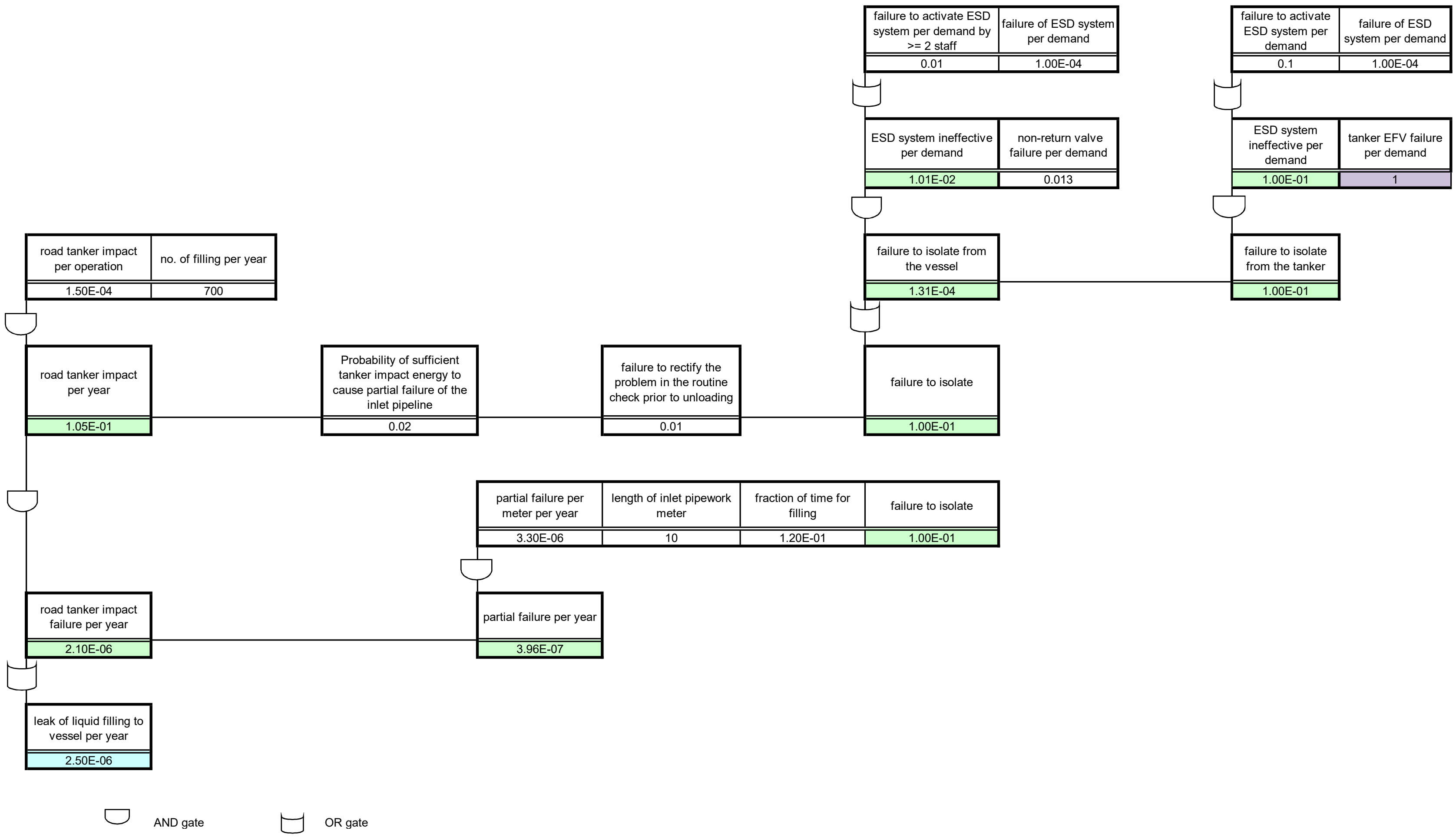
Guillotine failure of Flexible Hose during Unloading to the LPG vessel (LPG Filling Station)



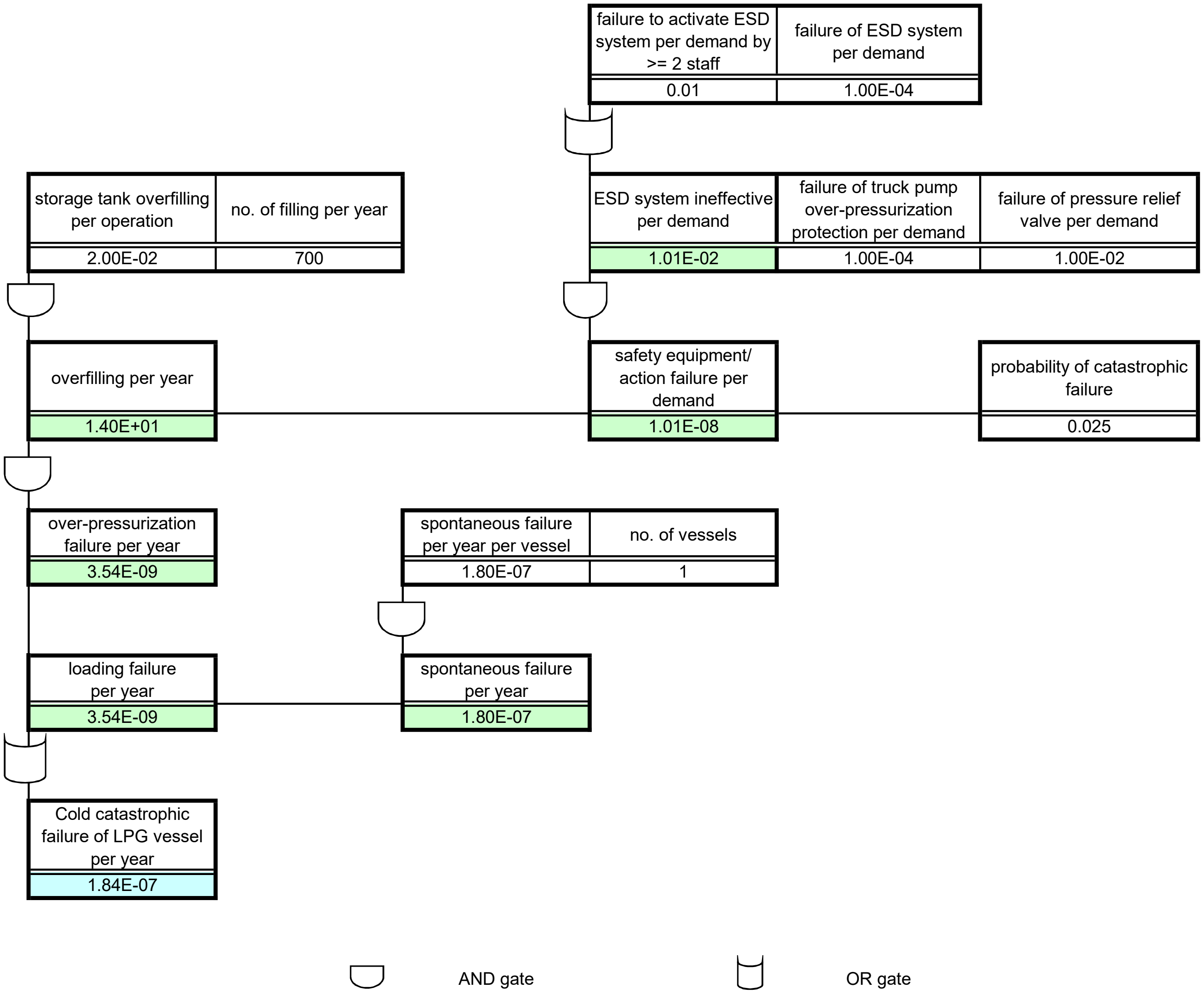
Partial failure of Flexible Hose during Unloading to the LPG vessel (LPG Filling Station)



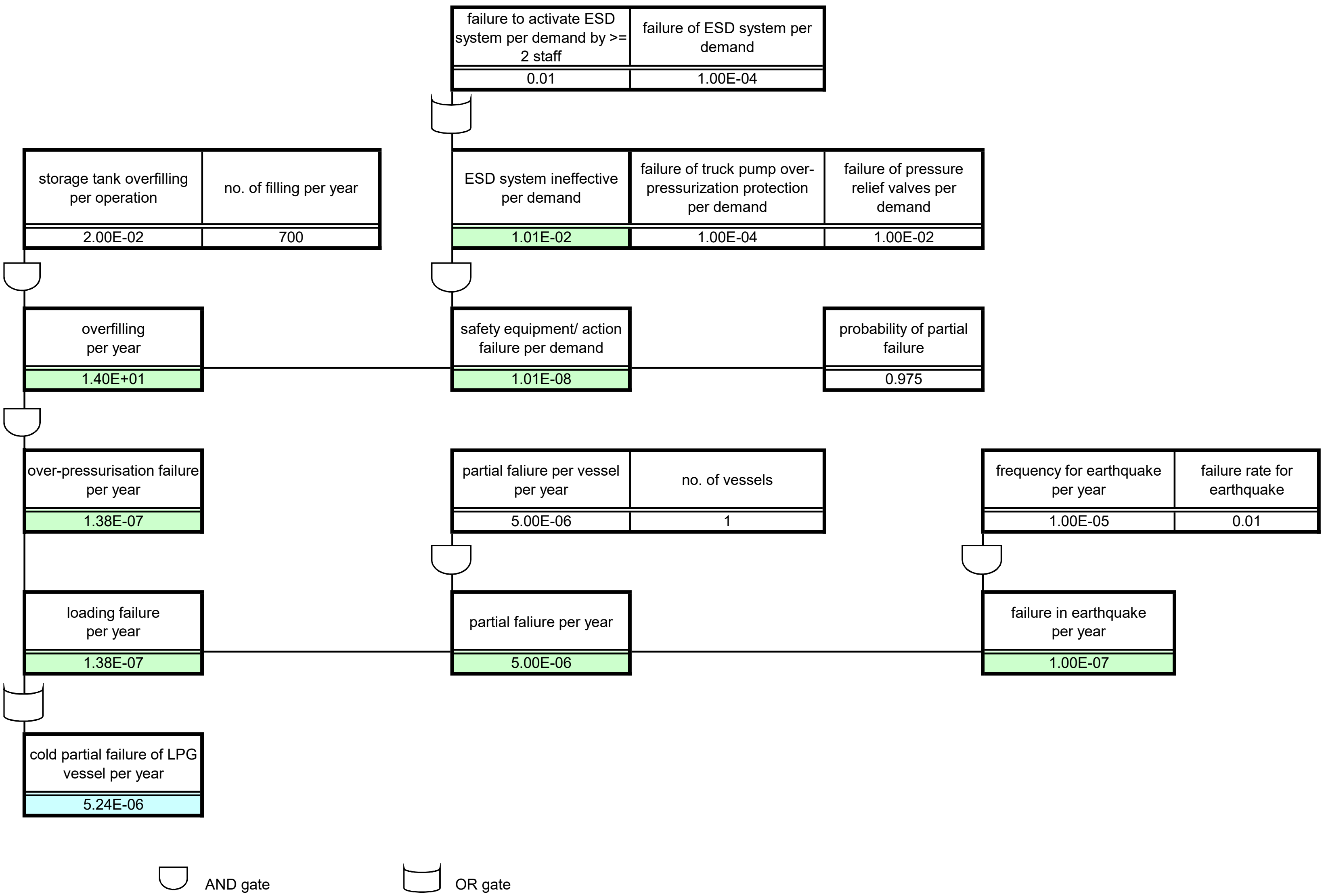
Guillotine failure of Inlet Pipeline (LPG Filling Station)



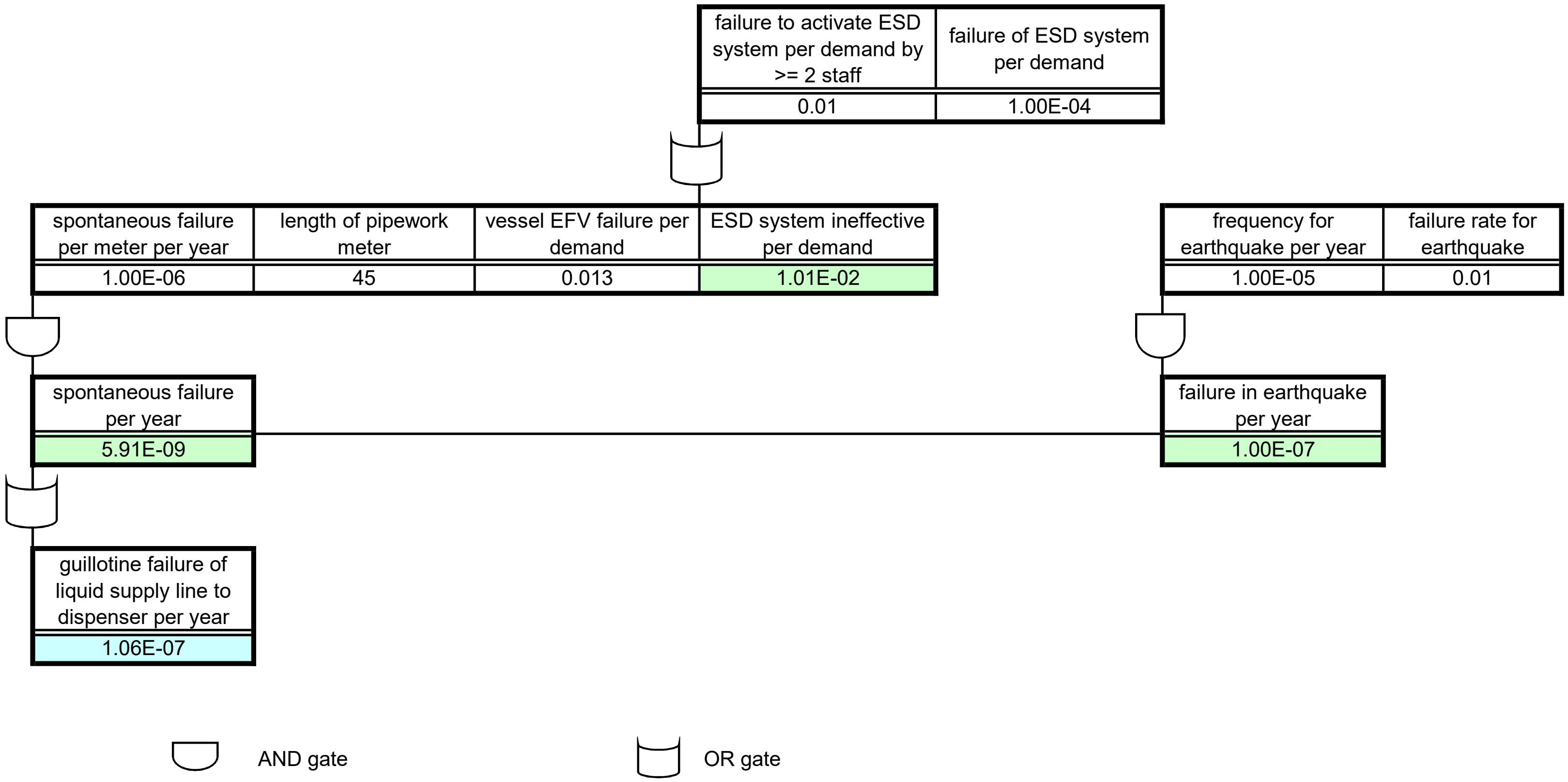
Partial failure of Inlet Pipeline (LPG Filling Station)



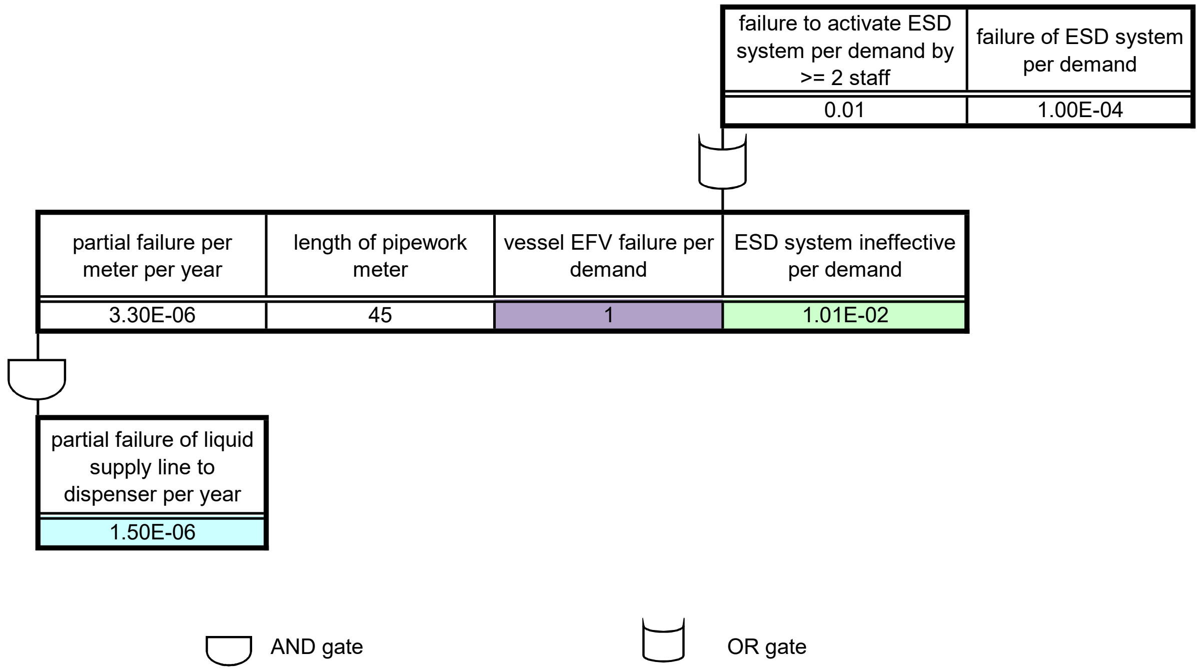
Cold Catastrophic Failure of LPG Vessel (LPG Filling Station)



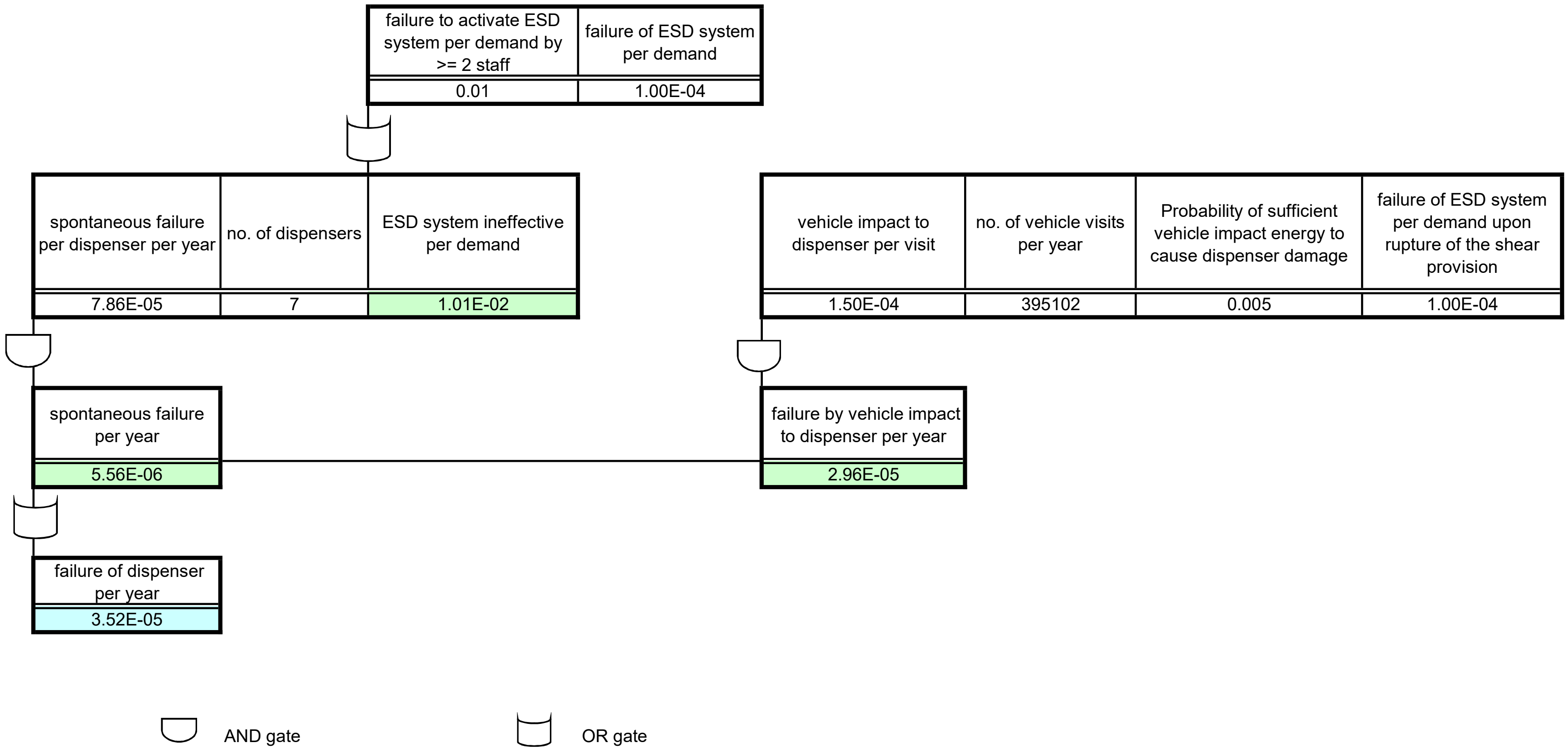
Partial Failure of LPG Vessel (LPG Filling Station)



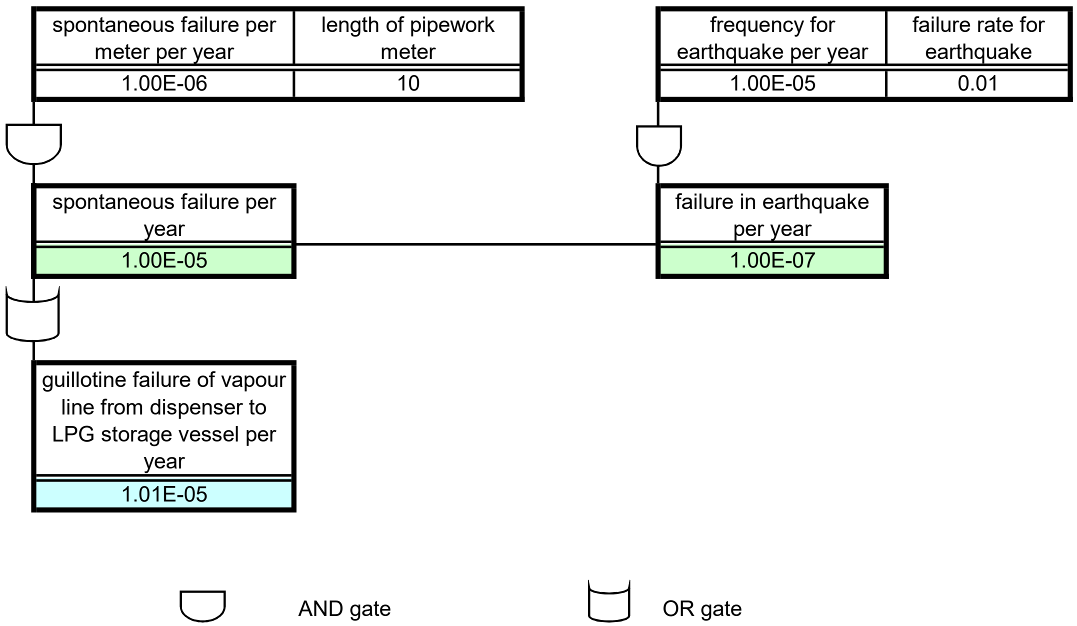
Guillotine failure of the Liquid Supply Pipeline to the Dispenser (LPG Filling Station)



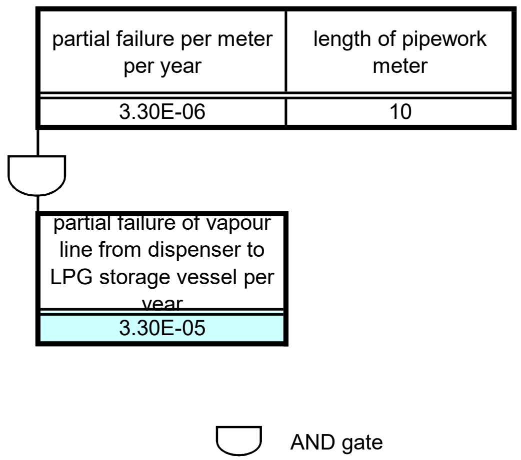
Partial failure of the Liquid Supply Pipeline to the Dispenser (LPG Filling Station)



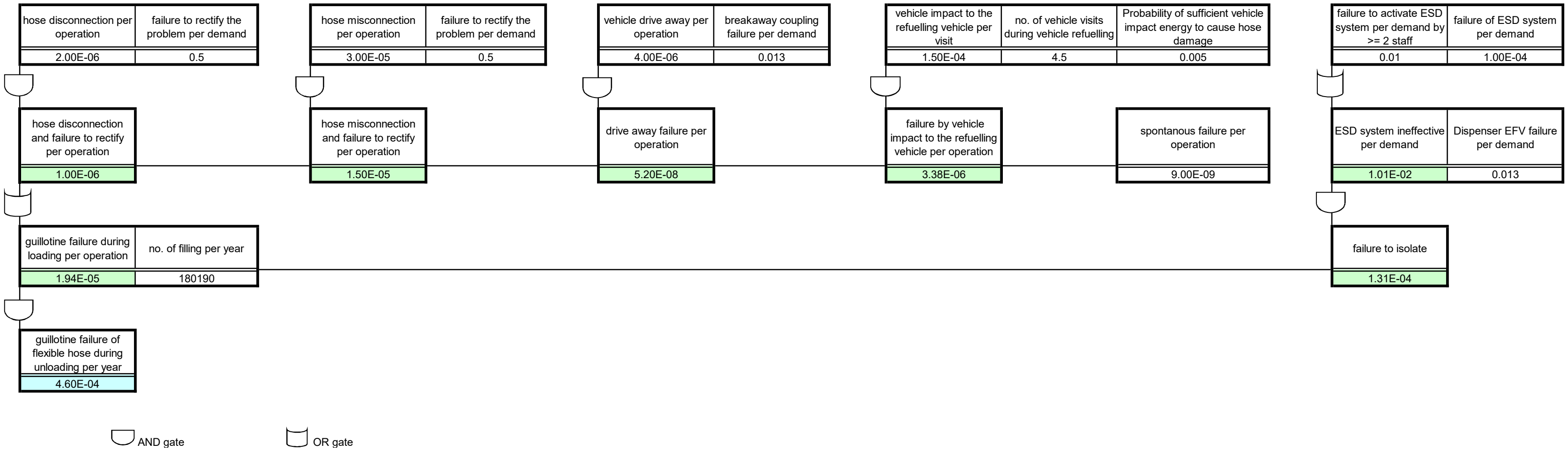
Failure of the Dispenser (LPG Filling Station)



Guillotine failure of Vapour Line from Dispensers to LPG Storage Vessel



Partial failure of Vapour Line from Dispensers to LPG Storage Vessel



Guillotine failure of Flexible Hose during Filling to the LPG Vehicle (LPG Filling Station)