APPENDIX 13.4 HAZARD TO LIFE ASSESSMENT FOR A PROPOSED GREEN FUEL STATION (GFS)

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1. INTRODUCTION

1.1 Background

1.1.1.1 The proposed green fuel station (GFS) with provision of LPG filling facilities is located at the southern boundary of the TKO 137. The GFS stores LPG in bulk quantities of less than 25 tonnes. It is classified as a Notifiable Gas Installation (NGI) under the Gas Safety Ordinance (Cap. 51) (GSO), but not Potentially Hazardous Installation (PHI) under Chapter 12 of the HKPSG. For planning the location of GFS with LPG filling facilities, Section 3.7 of Chapter 12 of the HKPSG has listed some general requirements, including the applicable separation distances between the LPG filling facilities and different types of land uses. Nonetheless, the suitability of incorporating LPG filling facilities in a filling station and the separation distance from other land uses are still subject to the outcome of a QRA.

1.2 Scope of Work

1.2.1.1 The Hazard to Life Assessment requirements for the GFS are shown below:

(a) Identify hazardous scenarios associated with operation of the GFS and then determine a set of relevant scenarios to be included in a QRA;

(b) Execute a QRA of the set of hazardous scenarios determined in (a), expressing population risks in both individual and societal terms;

(c) Compare individual and societal risks with the criteria for evaluating hazard to life as stipulated in Annex 4 of the TM; and

(d) Identify and assess practicable and cost-effective risk mitigation measures.

1.2.1.2 The following boundaries have been set for this assessment:

(a) The risks associated with the transport of LPG by road tankers have been restricted to those related to their final approach to the GFS; and

(b) The risk assessment has been limited to those events that have the potential of causing off-site fatalities.

1.3 Hong Kong Risk Guidelines (HKRG)

1.3.1.1 Annex 4 of the EIAO-TM specifies the Individual and Societal Risk Guidelines. The Hong Kong Government Risk Guidelines (HKRG) per the EIAO TM Annex 4 states that the individual risk is the predicted increase in the chance of fatality per year to an individual due to a potential hazard. The individual risk guidelines require that the maximum level of individual risk should not exceed 1 in 100,000 per year i.e. 1×10^{-5} per year. Societal risk expresses the risks to the whole population. It is expressed in terms of lines plotting the cumulative frequency (F) of N or more deaths in the population from incidents at the installation. Two F-N risk lines are used in the HKRG that demark “Acceptable” or “Unacceptable” societal risks. To avoid major disasters, there is a vertical cut-off line at the 1,000 fatality level extending down to a frequency of 1 in a billion years. The intermediate region indicates the acceptability of societal risk is borderline and should be reduced to a level which is “as low as reasonably practicable” (ALARP). It seeks to ensure that all practicable and cost-effective measures that can reduce risk are considered. The HKRG is presented graphically in **Plate 1.1**.

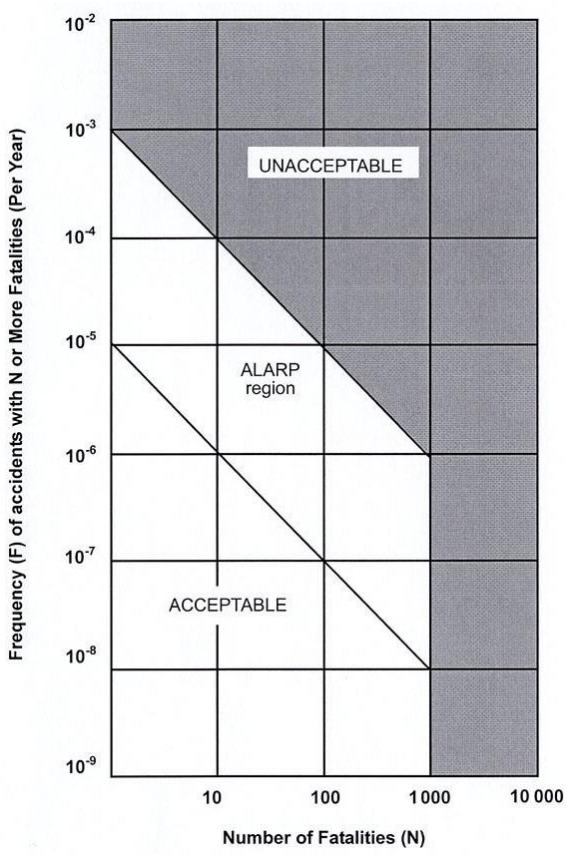

Plate 1.1 Societal Risk Guidelines

1.4 Assessment Approach

1.4.1 The QRA consisted of the following six main tasks:

(a) **Data / Information Collection and Update**: Collected relevant data / information necessary for the hazard assessment;

(b) **Hazard Identification**: Identified a credible set of hazardous scenarios associated with the GFS;

(c) **Frequency Estimation**: Estimated the frequencies of each hazardous event leading to fatalities based on the collected data with the support of justifications through the review of historical accident data and previous hazard assessment of similar projects;

(d) **Consequence Analysis**: Analysed the consequences of the identified hazardous scenarios;

(e) **Risk Integration and Evaluation**: Evaluated the risks associated with the identified hazardous scenarios. The evaluated risks were compared with the HKRG Risk Guideline to determine their acceptability; and

(f) **Identification of Mitigation Measures**: Where necessary, risk mitigation measures were identified and assessed to comply with the "as low as reasonably practicable" (ALARP) principle used in the HKRG. Practicable and cost-effective risk mitigation measures were identified and assessed as necessary. The risk outcomes of the mitigated case were reassessed to determine the level of risk reduction.

1.4.1.1 The hazard assessment covered the following two scenarios:

- Year 2035* (Construction phase) – The risk imposed by the operation of the proposed green fuel station (GFS) to the existing, committed and planned population in 2035.

- Year 2041 (Operational phase) – The risk imposed by the operation of the proposed green fuel station (GFS) to the existing, committed and planned population in 2041. This scenario took into account the full population intake of the proposed development with all the planned land users being considered.

*The Project would be commissioned in phases with the construction work scheduled for commencement in Year 2025 and completion by Year 2041 for full population intake. Based on the latest phasing plan, the earliest population intake of the proposed development in the vicinity of the GFS is 2035, which is at the same time as the commencement of GFS. Therefore, Year 2035 was selected as the assessment year of construction phase of the Project for risk assessment associated with the proposed GFS.

2. SITE DESCRIPTION

2.1 Study Area

2.1.1.1 The proposed green fuel station (GFS) with provision of LPG filling facilities is located at the southern boundary of the TKO 137. Study area of 200 m radius from the GFS was adopted as shown in **Plate 2.1**.

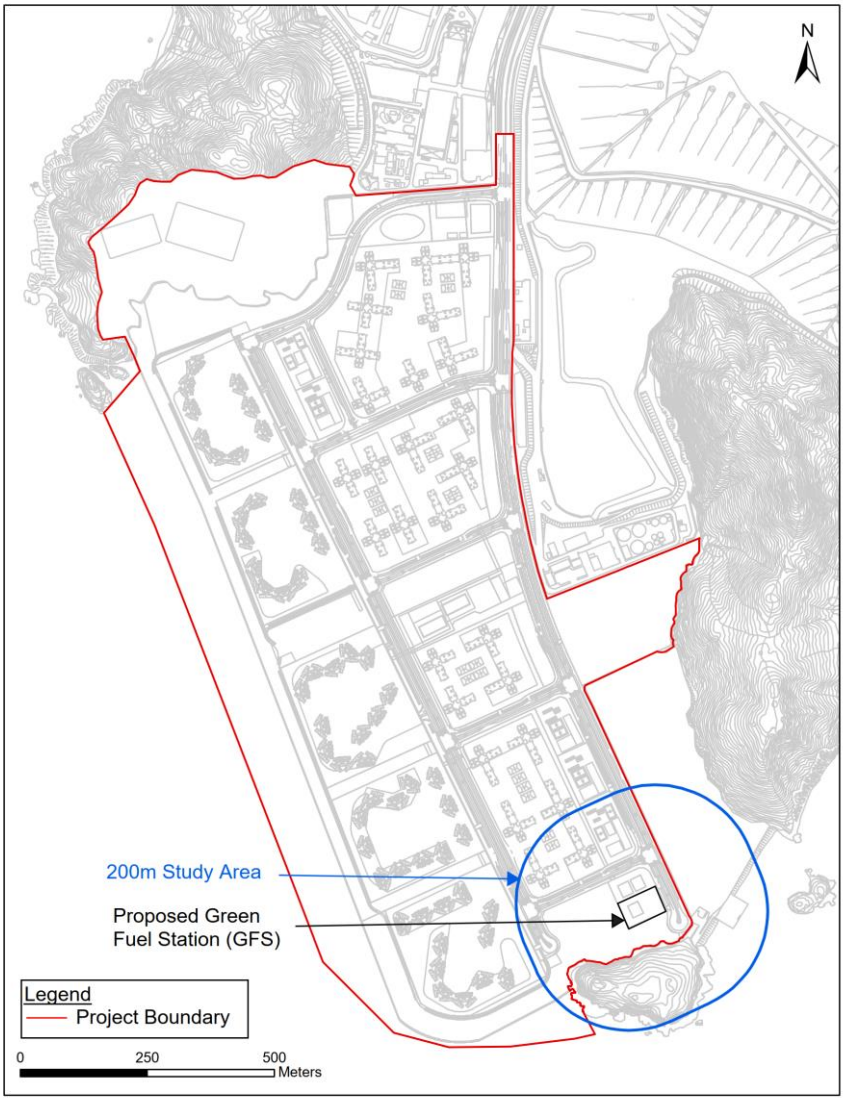

Plate 2.1 Site Location Plan

2.2 The Green Fuel Station

2.2.1.1 According to LPG throughput estimates, the proposed GFS will include two 25.4kL (water capacity) underground LPG storage vessels, which will be filled to the maximum permissible level (85% of the maximum capacity). There will also be six LPG dispensers and twelve dispensing nozzles for vehicle refuelling in the station.

2.2.1.2 The storage vessels will be designed, manufactured and tested in accordance with the requirements of the Gas Standard Office (GSO) of Electrical and Mechanical Services Department (EMSD). According to the gas safety requirements as stated in Section 3.7.2 of Chapter 12 in HKPSG, the vent pipes of pressure relief valves for the underground storage vessel will not be obstructed by any obstacles, and the discharge outlets of the vent pipes

will be at least 4.5m from any openings of a building or any non-flameproof electrical equipment.

2.3 LPG Delivery and Transfer

2.3.1.1 LPG will be delivered to the GFS by road tankers. The maximum capacity of the road tanker is about 9 tonnes. Based on the estimates, it is assumed that around 610 vehicles will use the LPG filling facilities, the daily LPG consumption will be around 17 tonnes and that 1-2 LPG deliveries will be necessary. Thus, the annual LPG deliveries of 730 was assumed in this assessment.

2.3.1.2 Based on an LPG pumping rate of 200 L / minute, the LPG road tanker's residence time at each GFS will be around 85 minutes, including 70 minutes for LPG unloading and another 15 minutes spent on site for setting up and preparation.

2.3.1.3 The road tankers will be operated in accordance with the standard requirements of the stations' operator. The standard procedures for the LPG delivery are summarised as follows:

(a) Two persons, the driver and his assistant, will be present during the delivery operation;

(b) A dedicated unloading area will be available for the unloading operation. There is a possibility of road tankers reversing in the unloading area. Road tankers will face towards run-out so that it may leave rapidly should it be required to do so;

(c) The condition of all connections and hoses will be checked by the driver;

(d) The storage vessel will be filled to a maximum of 85% of its liquid level capacity; and

(e) During delivery, the driver will wait in close proximity to the "emergency-cut-off switch" while the assistant attends to the delivery process.

2.4 Population

2.4.1 Surrounding Populations

2.4.1.1 Societal risk is a measure of the consequence magnitude and the frequency of the hazardous events. To establish the impact of any release (expressed as the number of people likely to be affected) in the future, it is necessary to have a good knowledge of the future surrounding population levels. These include residential population, government, institutional or community population, education and transport population but exclude staff of the GFS since they are considered as voluntary risk takers.

2.4.1.2 The locations of population groups and roads considered for both assessment years are presented in **Plate 2.2**. Details on the estimated population for each population group are provided in **Annex A**.

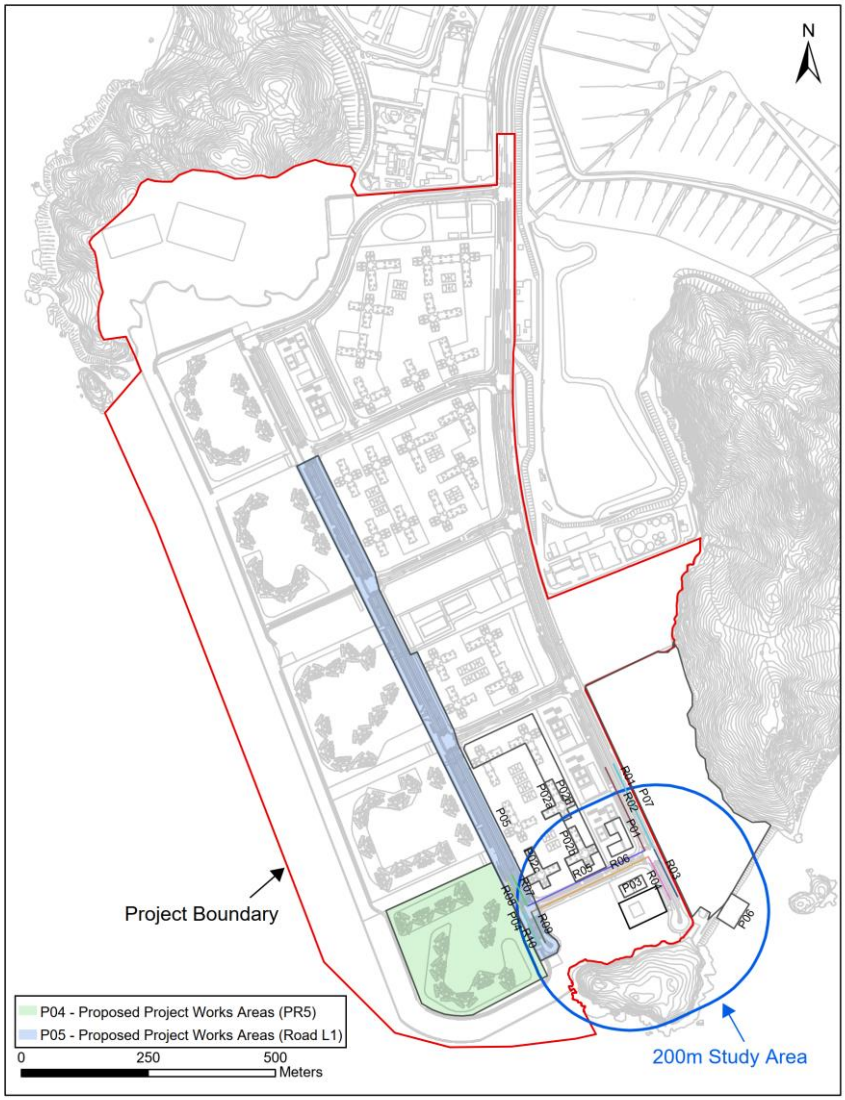

Plate 2.2 Locations of Population Groups and Road

Land and Building Population

2.4.1.3 Estimation of land and building populations was based on the latest information provided in the development schedule of the Draft RODP. An average of 5% population was considered to be outdoor for residential, institution and industrial population, while 100% population was assumed to be outdoor for construction workers and workers at the planned desalination plant.

Table 2.1 Land and Building Population Data

ID	Description	Population	
		Year 2035	Year 2041
P01	Secondary School	2412	2412
P02	Public Housing (PU6)		
P02a	Block 3	3230	3230
P02b	Block 5	3230	3230
P02c	Block 6	3230	3230
P02d	Podium 1	2452	2452

ID	Description	Population	
		Year 2035	Year 2041
P03	132kV Primary ESS	0	0
P04	Proposed Project Works Areas (PR5)	150	-
P05	Proposed Project Works Areas (Road L1)	150	-
P06	Explosives Off-loading Pier	0	0
P07	Desalination Plant	160	160

Road Population

2.4.1.4 The traffic data was based on the latest Annual Traffic Census (ATC) published by Transport Department (TD) [1] and the Traffic Impact Assessment (TIA) report prepared for this Assignment. The traffic population was predicted based on the following equation:

$$Traffic\ Population = \frac{No.of\ Person\ per\ vehicle \times No.of\ Vehicle\ per\ hour \times Road\ Length}{Speed}$$

2.4.1.5 Based on the latest ATC [1], the occupancies for each vehicle type and vehicle mix were taken at the core station no. 5021 (Tseung Kwan O Tunnel (from Toll Plaza to Tseung Kwan O Tunnel Rd RA)) to represent the road traffic for this assessment.

2.4.1.6 The traffic population was assumed to be 100% outdoor. The estimated road population considered for both assessment years are presented in **Table 2.2** and the detailed calculations are provided in **Annex A**.

Table 2.2 Estimated Road Population

ID	Description	Traffic Speed (km/hr)	Maximum Population			
			Year 2035		Year 2041	
			Daytime	Night-time	Daytime	Night-time
R01	Road L8	50	18	13	10	9
R02		50	17	12	12	10
R03		50	7	7	7	7
R04		50	7	7	7	7
R05	Road L7	50	26	17	13	11
R06		50	27	19	11	10
R07	Road L1	50	-	-	9	9
R08		50	-	-	9	9
R09		50	-	-	7	7
R10		50	-	-	7	7

2.4.2 Time Modes

2.4.2.1 Four representative time modes as presented in **Table 2.3** were applied in this hazard assessment to address the variation in levels of activities that could lead to a release and the variation in population in the assessment area with time.

Table 2.3 Definitions of Time Modes

Time Period	Definition	Proportion of Time
Weekday Day	Mon-Fri, 7am-7pm	35.71%
Weekday Night	Mon-Fri, 7pm-7am	35.71%
Weekend Day	Sat-Sun, 7am-7pm	14.29%
Weekend Night	Sat-Sun, 7pm-7am	14.29%

2.5 Meteorology

2.5.1.1 Meteorological data is required for consequence modelling and risk calculation. Consequence modelling (dispersion modelling) requires wind speed and stability class to determine the degree of turbulent mixing potential whereas risk calculation requires wind-rose frequencies for each combination of wind speed and stability class.

2.5.1.2 Meteorological data was obtained from Tseung Kwan O Weather Station where wind speed, stability class, weather class and wind direction are available. This data represented the weather conditions over a five-year period (i.e. between 2019 – 2023). Six combinations (2B, 1D, 3D, 6D, 2E and 1F) and five combinations (1D, 3D, 5D, 2E and 1F) of wind speed and stability class were chosen for daytime and night-time meteorological conditions respectively. These combinations were considered adequate to reflect the full range of observed variations in these quantities. It is not necessary and efficient to consider every combination observed. The principle is to group these combinations into representative weather classes that together cover all conditions observed.

2.5.1.3 Once the weather classes have been selected, frequencies for each wind direction for each weather class can then be determined. The frequency distributions for the daytime and night-time meteorological conditions are summarised in **Table 2.4**.

Table 2.4 Weather Class-Wind Direction Frequencies at Tseung Kwan O Weather Station

Daytime							
Direction	**2B**	**1D**	**3D**	**6D**	**2E**	**1F**	**Total (%)**
0 – 30	3.60	1.05	1.95	0.06	1.33	1.91	9.9
30 – 60	7.54	1.05	4.74	0.02	2.10	1.40	16.8
60 – 90	12.84	1.10	5.25	0.07	1.79	1.15	22.2
90 – 120	7.91	1.05	2.13	0.02	0.53	0.77	12.4
120 – 150	3.22	0.55	1.10	0.04	0.40	0.53	5.8
150 – 180	1.71	0.36	0.53	0.01	0.26	0.33	3.2
180 – 210	8.70	0.68	1.45	-	0.18	0.41	11.4
210 – 240	6.97	0.71	2.17	-	0.51	0.59	10.9
240 – 270	1.03	0.39	0.48	-	0.21	0.41	2.5
270 – 300	0.42	0.17	0.09	-	0.03	0.20	0.9
300 – 330	0.24	0.16	0.08	-	0.02	0.42	0.9
330 – 360	0.85	0.35	0.44	-	0.31	0.94	2.9
All (%)	55.0	7.6	20.4	0.2	7.7	9.1	100.0

Night-time						
Direction	**1D**	**3D**	**5D**	**2E**	**1F**	**Total (%)**
0 – 30	0.37	1.02	0.02	5.34	10.7	17.4
30 – 60	0.22	1.98	0.07	9.04	6.9	18.2
60 – 90	0.30	1.64	0.03	5.71	4.3	12.0
90 – 120	0.26	0.55	0.01	2.72	3.0	6.5
120 – 150	0.05	0.47	0.03	2.49	2.9	6.0
150 – 180	0.03	0.23	0.02	1.51	1.7	3.5
180 – 210	0.02	0.15	-	1.24	1.9	3.3
210 – 240	0.04	0.29	-	4.00	4.6	9.0
240 – 270	0.04	0.03	-	3.42	4.7	8.2
270 – 300	0.08	0.02	-	0.28	2.1	2.5
300 – 330	0.11	0.02	-	0.16	4.8	5.1
330 – 360	0.26	0.15	-	1.07	6.8	8.3
All (%)	1.8	6.5	0.2	37.0	54.5	100.0

3. HAZARD IDENIFICATION AND ANALYSIS

3.1 Introduction

3.1.1.1 A hazard is described as the property of a material or activity with the potential to do harm. A release of flammable gas such as LPG has the potential to cause fire or explosion if ignited. Without ignition, the gas vapours will disperse harmlessly. Under normal conditions, the LPG at the GFS will be stored and handled in contained and controlled manners. For LPG to pose a hazard to the people in the surrounding area, a release must occur as a result of a failure of that containment or as a result of faulty transfer procedures.

3.1.1.2 This section of the report summarises all possible failure cases and associated failure rates that could lead to a release of LPG. The failure rates adopted throughout this report were quoted from the paper "*Quantitative Risk Assessment for LPG Installations (Reeves, Minah and Chow, 1997)*" [2]. Furthermore, references for certain frequencies were drawn from approved EIA Reports [3][4] and QRA studies [5][6] where necessary and appropriate. In addition, possible initiating events were identified.

3.2 Behaviour of LPG Releases

3.2.1.1 LPG is a mixture of butane and propane. The gas is twice as heavy as air. For a release of LPG, the nature of the combustion will depend on the timing of ignition and the size of the release.

3.2.1.2 A release of several tonnes of LPG, if ignited immediately, will produce a fireball. Initially, the gas concentration in the mixture will be above the Upper Flammability Limit (UFL). As burning occurs around the edges of the release, this will entrain more air into the mixture and more combustion will take place. The process accelerates until the mixture rising above the ground as a ball of fire. A fireball may also result from a boiling liquid expanding vapour explosion (BLEVE). This results from the bursting of a vessel (owing to a high internal pressure and a weakening of the vessel material, as a result of a fire for example). The vessel contents rapidly vaporise and are ignited.

3.2.1.3 If not ignited immediately, the gas will disperse and dilute. If ignition occurs when the gas concentration is between Lower Flammability Limit (LFL) and Upper Flammability Limit (UFL), a flame front will propagate to produce a flash fire.

3.2.1.4 For small releases, immediate ignition will produce a long vigorous jet flame from the point of release. As for large releases, delayed ignition will generally produce a flash fire.

3.2.1.5 For all sizes of release, the LPG will disperse harmlessly if there is no source of ignition.

3.3 Hazard Identification

3.3.1 Spontaneous Failures

<u>Failure of Storage Vessel</u>

3.3.1.1 Failure of a vessel can be resulted from: (i) a cold catastrophic failure leading to instantaneous release of the full inventory and (ii) a partial failure leading to continuous release of the full inventory via a 25mm hole. The causes of failure are summarised as follows:

(a) Spontaneous failure due to corrosion, fatigue, etc.

(b) Overfilling

(c) Earthquake

Failure of Road Tanker

3.3.1.2 The causes of a road tanker failure are similar to that of a storage vessel. Furthermore, road tankers are vulnerable to collision with other road vehicles during delivery.

Guillotine Failure of Liquid Filling Line to Storage Vessel

3.3.1.3 Failure of the liquid line is possible due to corrosion or fatigue, vehicle impact and external events. Only guillotine failure of the LPG pipework was considered in this assessment as partial failure of pipework is deemed as an insignificant contributor towards the overall risk levels. The failure would result in LPG leaking from the full bore of the pipe. Moreover, part of the pipework will be installed aboveground. Failure of the aboveground portion of the liquid filling line can be resulted from vehicle impact while failure of the underground portion of the liquid filling line can be resulted from earthquake.

Guillotine Failure of Liquid Line to Dispenser

3.3.1.4 The cause of failure of this line is similar to that of the liquid filling line to the storage vessel, which is mainly due to either corrosion or fatigue. Moreover, the failure of the underground portion of the pipework can be resulted from external events while the aboveground portion of the pipework can result from vehicle impact. The failure would result in LPG leaking from the full bore of the pipe.

Guillotine Failure of Liquid Line from Tanker Pipe to Loading Hose

3.3.1.5 The cause of failure of this line is similar to that of the liquid filling line to the storage vessel, which is mainly due to either corrosion or fatigue. Moreover, the failure can be due to vehicle impact and other external events.

Failure of Dispenser

3.3.1.6 The cause of failure of the dispenser could be corrosion, fatigue, vehicle impact (vehicle visiting the filling station) and other external events, which would result in a release from the dispenser pipework.

Failure of Flexible Hose

3.3.1.7 The loading hose could fail due to the following causes:

(a) Fatigue

(b) Hose misconnection

(c) Hose disconnection during loading or unloading process

(d) Vehicle impact

(e) Operator / driver error

Failure of Vapour Return Line

3.3.1.8 Similar to the liquid line, failure of the vapour return line is credible which would result in vapour leak equivalent to the diameter of the line. Moreover, the failure of vapour return line can be resulted from external events.

Release from Storage Vessel Pump Flange

3.3.1.9 A release from the submersible pump on the storage vessel is not credible as the LPG release would flow back into the storage vessel. However, the release however would take place from the flanges associated with the pump fitting.

Release from Storage Tank Drain Valve

3.3.1.10 The storage tank drain valve is open to drain out accumulated water several times per year. Release from the drain valve is possible due to human error, where operator fails to close it by mistake.

Leak from Vehicle Vessel

3.3.1.11 Similar to the failure of the LPG storage vessel and road tanker, a leak from a vehicle vessel could be spontaneously caused by impact by other vehicles or refuelling error. However, the LPG inventory of a vehicle vessel is small compared to that of the storage vessel and road tanker, and therefore the effect is insignificant.

3.3.2 Loading / Unloading Failures

3.3.2.1 When LPG releases occur as a direct result of the road tanker unloading operation, the failure events can be regarded as loading failures. The failure events that were considered in the assessment include:

(a) Hose misconnection and disconnection error

(b) Tanker drive away error

(c) Road tanker collision

(d) Vehicle impact with road tanker during unloading

(e) Storage vessel overfilling

(f) Over-pressurisation of pipework

Hose Misconnection and Disconnection Error

3.3.2.2 A significant release of LPG during its transfer from the road tanker to the storage vessel could occur as a result of the failure of the transfer hoses and coupling, human error or vehicle impact.

Tanker Drive away Error

3.3.2.3 This error could be resulted from: (i) repositioning of the road tanker during delivery; and/or (ii) the driver driving the road tanker away before the delivery is completed.

Road Tanker Collision

3.3.2.4 Road tanker collision refers to an event in which an LPG road tanker strikes the facilities of the filling station and causes damages to these facilities. Provision of a dedicated road tanker parking area and unloading area, implementation of speed control, control on the use of dispenser system and implementation of a rigorous training system are safety measures commonly adopted to avoid serious collision incidents. The likelihood of a road tanker collision leading to the failure of the road tanker itself is considered to be insignificant. Underground facilities such as LPG storage vessel and pipework would not be affected by this event since they are installed underground. Collision of an LPG road tanker with other

road tankers is considered not possible as concurrent unloading of liquid fuels and LPG at the filling station is not allowed in Hong Kong.

Vehicle Impact with Road Tanker during Unloading

3.3.2.5 There is a possibility that a vehicle collides with the road tanker during unloading operation. When this happens, a release of LPG could occur.

Storage Vessel Overfilling

3.3.2.6 Failure of the LPG storage vessel could occur as a result of overfilling of LPG from the road tanker to the vessel.

Over-pressurisation of Pipework

3.3.2.7 Over-pressurisation could be caused by continuing unloading operation when a storage vessel is overfilled or when the isolation valves at the receiving storage vessel are closed. It was considered that the probability of the pipework over-pressurisation would be negligible with all the safety system to be provided at the GFS, and therefore not considered in this assessment.

3.3.3 External Events

3.3.3.1 An LPG release event could occur due to external events and the consequences could be catastrophic. The related external events are listed as follows:

(a) Earthquake

(b) Aircraft crash

(c) Landslide

(d) Severe environmental event such as typhoon or tsunami

(e) Subsidence

(f) External fire

(g) Vehicle Impact

(h) Lightning

(i) Third Party Damage

Earthquake

3.3.4 According to Reeves et al. (1997) [2], an earthquake of Modified Mercalli Intensity (MMI) VIII could provide enough intensity to result in damage to the storage vessel or pipework. Therefore, earthquake was considered in this assessment.

Aircraft Crash

3.3.4.1 Aircrafts crashing into the GFS during take-off and landing as well as airway accidents along the arrival / departure flight paths were taken into account in this assessment. The method given in HSE (1997) [7] for the calculation of aircraft crash frequency was adopted.

Landslide

3.3.4.2 The GFS is bounded by open spaces, roads and buildings with no slope located in its vicinity. Therefore, the probability of landslide is negligible, and this external event was not further considered in this assessment.

Severe Environmental Event

3.3.5 According to BDEIA [3], loss of LPG content owing to severe environmental events such as typhoon or tsunami (i.e. a tidal wave following an earthquake) was considered to be insignificant as the LPG vessel will be installed underground and away from the seashore. Therefore, the probabilities of severe environmental events are very small or negligible and these were not further considered in this assessment.

Subsidence

3.3.5.1 Subsidence is usually slow in movement and such movement can be observed and remedial action can be taken in time. Therefore, the probabilities of subsidence are very small or negligible and these were not further considered in this assessment.

External Fire

3.3.5.2 External fire refers to the occurrence of a fire event that leads to the failure of the road tanker / vessel or other facilities. The key concern is the LPG road tanker being affected by external fires. In Hong Kong, LPG road tankers are covered with Chartek coating to ensure the tanker wall temperatures are kept sufficiently low. Fire extinguishers will also be provided in the GFS. The LPG closed-loop system will be shut down once there is an external fire threatening the station. Escalation due to fire occurring outside of the GFS was therefore considered not credible. Fire events, such as vehicle fire, within the GFS may cause damage to the LPG facilities and these are further elaborated in the “Escalation” section below.

Vehicle Impact

3.3.5.3 There is a possibility that a vehicle/ LPG road tanker strikes the facilities of the filling station and causes damages to the aboveground facilities, as well as vehicle impact into road tanker during unloading. Therefore, failure of aboveground facilities due to impact with vehicle/ road tanker, and failure of road tanker due to vehicle impact were considered in this assessment.

Lightning

3.3.5.4 The installation is expected to be protected with lightning conductors to safely earth direct lightning strikes. Besides, the proposed development would also provide shielding effect to prevent the GFS being struck by lightning. With sufficient protection system, no further consideration was given for the effect of lightning strike in this assessment.

Third Party Damage

3.3.5.5 Activities causing incidents such as work on other underground utilities, drilling for ground sampling, construction work on adjoining areas, etc. after the commission of GFS is not foreseen. Thus, third party damage was not further considered in this assessment.

3.3.6 Safety Features

3.3.7 Safety features to be installed in the LPG facilities of the GFS can act in different combination to mitigate LPG releases. The safety features considered in this assessment are listed as follows:

(a) Pressure relief valve

(b) Non-return valve

(c) Excess flow valve

(d) Emergency shutdown system

(e) Double-check filler valve

(f) Breakaway coupling

(g) Manual isolation system

Pressure Relief Valve

3.3.7.1 Relief valve is employed to ensure the vessel is not subject to an excessive internal pressure that may cause a failure as a result of overfilling. It also offers protection against excessive pressure build up within the vessel in case of fire situation.

Non-return Valve

3.3.7.2 Non-return valve on the liquid filling line can isolate release immediately. If it functions properly, there will be no significant consequence.

Excess Flow Valve

3.3.7.3 Excess flow valve installed on the road tanker and the storage vessel is expected to mitigate release from guillotine failure of the pipework or the flexible filling hose.

Emergency Shutdown System

3.3.7.4 Emergency Shutdown (ESD) system is installed on both the road tanker and the storage vessel. For a release from the road tanker, the emergency isolation system and the engine emergency stop system can be activated to isolate the release due to equipment failure and human error. For a release from the vessel, the emergency isolation system can be triggered to enable quick remote closure of all actuated valves at the station to mitigate the release at the road tanker unloading / filling point, the liquid supply line and the vapour return line of each dispenser, the liquid outlet / inlet and vapour return line on the vessel.

Double-check Filler Valve

3.3.7.5 Double-check filler valve is provided at the hose connection point on the liquid filling line to prevent release to be fed back from the vessel. The design of this valve is essentially two non-return valves in series.

Breakaway Coupling

3.3.7.6 One problem identified with road tankers and refilling vehicles is the possibility of road tankers and refilling vehicles being driven away whilst the hose is still connected, thereby causing damage to the facilities of the GFS and resulting in release of LPG. The breakaway

coupling is installed to prevent undue spillage of LPG owing to the movement of road tankers and vehicles.

Manual Isolation System

3.3.7.7 Manual valve is installed for the operators/ drivers to shut off the delivery connection manually in case of failure.

3.3.8 Human Error

3.3.8.1 When a failure of equipment or loading process occurs, it is possible for the operator to rectify the problem before a hazard event occurs. Human error is regarded as a failure case if the operator fails to rectify the problem.

3.3.9 Fire Protection / Fighting System

Water Spray System

3.3.9.1 The GFS will be installed with a water spray system with their own storage of water supply. When a water spray system is activated, the fire associated with equipment in the filling station such as pipeworks, dispensers and LPG vehicles can be extinguished or prevented from spreading towards a parked road tanker.

Fire Services

3.3.9.2 The fire services will be available within a few minutes in case of a fire. The extinction of fire by fire fighters prevents BLEVE from occurring. Besides, a street fire hydrant is assumed available nearby and fire service water inlet will be installed at the perimeter of the GFS to provide additional fire water supply.

Chartek Coating

3.3.9.3 Chartek coating is a safety feature of all road tankers. The coating has been reported to provide protection for at least 30 minutes in the case of a jet fire. The coating could prevent a hot spot from developing in a jet fire attack on the road tanker, which can cause thermal weakening of the road tanker wall leading to BLEVE.

3.3.10 Escalation

3.3.10.1 BLEVE of an LPG road tanker can happen if the road tanker is impinged by jet fire from the failure of aboveground LPG facilities listed below:

(a) Dispenser;

(b) Inlet filling pipework;

(c) Liquid supply line to dispenser;

(d) Flexible hose during loading to underground vessel;

(e) Liquid line from tanker to loading hose;

(f) Flexible hose during loading to vehicle is not considered as the jet flame produced will not impinge on the road tanker; and

(g) While Chartek coating can provide 30 minutes protection to the storage tank, the release and jet fire duration is less than 10 min in leak failure of an LPG vehicle.

Therefore, jet fire in leak failure of LPG vehicle does not lead to BLEVE of an LPG road tanker.

3.3.11 Summary

3.3.11.1 The possible hazard events for the day-to-day operations of the GFS have been identified and reviewed in previous sections. Only those possible failure cases considered to have the potential to cause off-site fatality are summarised in **Table 3.1**.

Table 3.1 Identified Failure Cases for the GFS

Failure Types	Failure Cases
Spontaneous Failure of Pressurised LPG Equipment	• Storage Vessel Failure • Road Tanker Failure • Pipework Failure • Dispenser Failure • Hose Failure • Vapour Return Line Failure • Release from Storage Vessel Pump Flange • Release from Storage Vessel Drain Valve
Loading / Unloading Failure	• Hose Misconnection Error • Hose Disconnection Error • Tanker Drive away Error • Road Tanker Collision during Unloading • Vehicle Impact with Tanker during Unloading • Storage Vessel Overfilling
External Event	• Earthquake MMI VIII • Aircraft Crash
Safety System Failure	• Pressure Relief Valve Failure • Non-return Valve Failure • Excess Flow Valve Failure • Emergency Shutdown System Failure • Double-check Filler Valve Failure • Breakaway Coupling Failure • Manual Isolation Valve Failure
Human Error	• Human Error
Fire Fighting System Failure	• Water Spray System Failure • Fire Services Failure • Chartek Coating Failure
Escalation	• LPG Road Tanker BLEVE Due to Fire in the Filling Facilities • LPG Road Tanker BLEVE Due to Jet Fire from Aboveground LPG Facilities

3.4 Hazard Analysis

3.4.1 Spontaneous Failure of Pressurised LPG Equipment

Storage Vessel Failure

3.4.1.1 A release of LPG could occur as a result of catastrophic failure or partial failure of the storage vessel and such a failure would lead to either a loss of entire contents of the vessel or a continuous release of LPG to atmosphere.

3.4.1.2 Failure rates of 1.8×10^{-7} per vessel year [2] and 5.0×10^{-6} per vessel year [2] were adopted for cold catastrophic failure and partial failure, respectively. It was assumed that the storage

vessels are nominally full for 30% of the time and at 60% of maximum inventory for the other 70% of time.

Road Tanker Failure

3.4.1.3 As discussed in **Section 3.3.1.2**, the definitions of catastrophic and partial failures of road tanker are similar to those of the storage vessel. It is generally considered that the catastrophic failure rate for LPG road tankers could be higher than that for a fixed storage vessel because of a) stresses experienced by the road tanker owing to vibration during transportation; and b) cyclic loading associated with filling/unloading the road tanker.

3.4.1.4 Failure rates of 2.0×10^{-6} per tanker year [2] and 5.0×10^{-6} per tanker year [2] were adopted for catastrophic tanker failure and partial failure of road tanker, respectively. The road tanker was modelled at maximum content for 20% of the time and at 50% of maximum inventory for the other 80% of the time.

Pipework Failure

3.4.1.5 Reeves et al. (1997) [2] indicated that releases from pipework partial failures were insignificant contributors to the overall risk levels. Therefore, only guillotine failure of LPG pipework was considered in this assessment. A generic rate of 1.0×10^{-6} per meter per year for guillotine failure of the pipework was adopted.

Dispenser Failure

3.4.1.6 The dispenser is essentially a metering device that consists of a hose with a self-sealing connector, four ball valves (with two flanges for each valve) and a certain length of rigid pipework. The only way to estimate the failure frequency would be to account for each of these components and add together. Assuming the dispenser is equivalent to 1m of small bore piping (<100mm) with two flanges joints and four ball valves with eight flange joints, a failure rate of 5.0×10^{-5} per hour for an LPG disperser is obtained with the following estimates:

(a) 1m piping * 1×10^{-10} per meter per hour [8]

(b) 10 flanges (8 from 4 ball valves, 2 from meter joints) * 3×10^{-7} per flange per hour [9]

(c) 4 ball valves * 0.5×10^{-6} per valve per hour [9]

3.4.1.7 Therefore, the dispenser failure rate was estimated as 5.0×10^{-6} × 8,760 hours = 4.38×10^{-2} per year.

Hose Failure

3.4.1.8 The effect of partial failure of the hose was neglected. A generic guillotine failure rate of flexible hose of 1.8×10^{-7} per transfer, for a 2-hour transfer, was assumed thus giving a guillotine failure rate of flexible hose of 9.0×10^{-8} per hour [2].

3.4.1.9 In addition, the vehicle loading process takes about 5 minutes (from the dispenser to the vehicle). Therefore, the guillotine failure rate of flexible hose for LPG loading to a vehicle was taken as 7.5×10^{-9} per transfer.

Vapour Return Line Failure

3.4.1.10 A generic failure rate of 1.0×10^{-6} per meter per year was adopted [2].

Release from Storage Vessel Pump Flange

3.4.1.11 A generic failure rate of 1.09×10^{-4} per flange per year[1] was adopted [10].

Release from Storage Vessel Drain Valve

3.4.1.12 For the operator failed to close the drain valve by accident, a failure rate of 2.0×10^{-5} per operation [11] was adopted.

3.4.2 Loading / Unloading Failures

Hose Misconnection Error

3.4.2.1 A significant release of LPG during its transfer from the road tanker to the storage vessel could occur as a result of the failure of the transfer hoses and coupling, human error, or vehicle impact. The likelihood of such an event was taken as 3.0×10^{-5} per operation [2].

Hose Disconnection Error

3.4.2.2 A rate of 2.0×10^{-6} per operation [2] was adopted for this failure case.

Tanker Drive-away Error

3.4.2.3 Tanker drive-away error refers to an event in which the tanker moves away with the hose still connected. It could result from the tanker driver inadvertently driving away before delivery is completed. It was considered that drive-away was unlikely. Even if such errors do occur, it is highly likely that the failure can be immediately rectified since the delivery process would not go unattended. A failure rate of 4×10^{-6} per operation [2] was adopted.

Tanker Collision during Unloading

3.4.2.4 A release of LPG cloud occurs as a result of an incident involving an LPG tanker and LPG equipment during delivery. The failure rate of tanker impact during unloading was assumed as 1.5×10^{-4} per delivery [2].

Vehicle Impact with Road Tanker during Unloading

3.4.2.5 A rate of 1.0×10^{-8} per operation [2] was adopted for the case that a vehicle impact into road tanker during unloading.

Overfilling of Storage Vessel

3.4.2.6 The practice on-site in unloading LPG to the underground storage vessel is that the vessel will only be filled to 85% of its maximum capacity. It was considered that the probability of the driver overfilling a storage vessel is low. A rate of 2.0×10^{-2} per operation [2] was adopted for this failure case.

3.4.3 External Events

Earthquake MMI VIII

3.4.3.1 A probability of 1.0×10^{-5} per year was adopted for the occurrence of an MMI VIII earthquake. The failure rate of pipework and partial failure of underground vessel owing to earthquakes

[1] Referencing the SPC/TECH/OSD/24 - accident/incident data from Health and Safety Executive (HSE) reviewed in March 2007, it stated the failure rate of pump flange is between 4.11×10^{-5} and 1.09×10^{-4} /flange year. Thus, a conservative value of 1.09×10^{-4} /flange year was assumed in this study as this is an updated value in March 2007 to reflect the failure frequency of a pump flange.

was assumed to be 0.01 [3], whereas the probability of failure of road tanker and the underground vessels was considered to be zero.

Aircraft Crash

3.4.3.2 The distance between the nearest arrival / departure flight path for the Hong Kong International Airport (HKIA) and GFS is approximately 0.5km. The distance between the GFS and HKIA is about 37.4km, which exceeds the criteria of 5 miles (8km) for the consideration of airfield accident. At such distances, the GFS would not come into the flight paths of the critical take-off and landing phases, and therefore only the background crash rate and airway crash rate were accounted for. The frequency of aircraft crash was estimated using the methodology of the HSE (1997) [7]. The model took into account specific factors such as the target area of the GFS and the distance between the GFS and the runway threshold. The aircraft crash frequency per year was calculated as:

Frequency (per year) = Background Crash Rate + Airway Crash Rate

Frequency (per year) = $(A \times B_i) + (A \times N_i \times R_i \times afac/ alt)$

Where,

A = Area of the GFS (4.41×10^{-3} km^2)

N = Number of aircraft movements per year

B_i = Background crash rate for aircraft (2×10^{-6} per year per km^2 [12])

R_i = Aircraft in-flight reliability (4.7×10^{-11} per year per km per aircraft movement [12])

afac = Area factor obtained from Table 9 of UK HSE report [12]

Alt = Mean altitude of aircraft (5 km)

3.4.3.3 The area factor (afac) is defined as the probability of a crash at a given location relative to the airway. With reference to Table 9 of UK HSE report [12], afac of 0.395 was adopted based on the corresponding x1 of 0.11, as estimated from the below equation:

x1 = x/ alt

Where,

x = Minimum horizontal distance from the nearest flight path to the GFS (0.5km)

Alt = Mean altitude of aircraft (5 km)

3.4.3.4 According to the statistic of Civil International Air Transport Movements of Aircraft [12], 427,766 movements were recorded in 2018. Thus, the aircraft crash frequency was estimated as 1.58×10^{-8} per year.

3.4.4 Safety System Failure

3.4.4.1 If the safety system operates as designed, then releases will not present an off-site hazard. There is, however, a potential for failure of the safety system. A typical safety system involves pressure relief valve, non-return valve, excess flow valve, emergency shutdown system, breakaway coupling and double-check filler valve.

Pressure Relief Valve Failure

3.4.4.2 The pressure relief valve avoids the LPG pipework or underground storage vessel from getting overpressure. A generic failure of 1.0×10^{-4} [2] for the pressure relief valve per demand was adopted.

Non-return Valve Failure

3.4.4.3 The non-return valve is intended to avoid the back flow of LPG. A generic failure rate of 0.013 per demand [2] was adopted.

Excess Flow Valve Failure

3.4.4.4 The excess flow valve installed at the road tanker and the storage vessel is expected to be functional when guillotine failure of pipework or flexible hose occurs. Considering the different testing interval for road tankers and storage vessels, generic failure rates of 0.013 and 0.13 per demand [2] were adopted for the road tanker and the storage vessel respectively.

Emergency Shutdown System Failure

3.4.4.5 A generic failure rate of 1.0×10^{-4} per demand [2] was assumed.

Breakaway Coupling Failure

3.4.4.6 Generic failure rates of 0.013 and 0.13 per demand [2] were adopted for the road tanker and the dispenser respectively.

Double-check Filler Valve Failure

3.4.4.7 A double-check filler valve prevents the LPG release to be fed back from the storage vessel. The design has two non-return valves in series. A generic failure rate of 2.6×10^{-3} per demand [2] for common mode failure was adopted.

Manual Isolation Valve Failure

3.4.4.8 Manual valve is installed for operators / drivers' intervention in case of failure. A generic failure rate of 0.5 per demand [2] was assumed.

3.4.5 Human Error

3.4.5.1 According to Appendix III of Reactor Safety Study prepared by US Nuclear Regulatory Commission in 1975, an estimation of average error rate of 0.2 to 0.3 was assumed for nuclear power plant personnel in a high-stress situation [11]. In that study, it also stated that the range of 0.2 to 0.3 was to be considered conservative. In this assessment, a probability of 0.2 per demand[2] [3] was assumed to account for the human error in which operators fail to rectify the problem before any hazard event occurs.

[2] According to the EIA study "Proposed Headquarters and Bus Maintenance Depot in Chai Wan" (BDEIA), by Ling Chan + Partners Limited. (2001)", a probability of 0.2 is assumed for human error. Moreover, from Appendix III of Reactor Safety Study prepared by US Nuclear Regulatory Commission in 1975, an estimation of average error rate of 0.2 to 0.3 was assumed for nuclear power plant personnel in a high-stress situation. In that study, it also stated that the range of 0.2 to 0.3 was to be considered conservative. In this study, a probability of 0.2 (per demand) was assumed to account for the human error in which operators fail to rectify the problem before any hazard event occurs.

3.4.6 Fire Fighting System Failure

Water Spray System Failure

3.4.6.1 A generic failure rate of 1.5×10^{-2} per demand [2] was adopted to account for the common problems of the water spray system: blocked nozzles and malfunction of the fire detectors.

Failure of Fire Services

3.4.6.2 It was assumed that the fire services would always be available, and therefore zero probability was applied for the failure case of "fire services arrive late". A generic failure rate of 0.5 per demand [2] was assumed for the fire services to be ineffective against a fire attack.

Gas Detection System

3.4.6.3 The system is identified as an additional safety device for the operator to take emergency actions when LPG release occurs. Since the system would not induce additional likelihood of failure events, the system would not be included into the fault tree analysis.

Chartek Coating Failure

3.4.6.4 A generic failure rate of 0.1 per demand [2] was applied for the Chartek coating fails to prevent a hot spot from developing on the road tanker in a jet fire attack owing to poor maintenance.

3.4.6.5 A summary of the identified failure cases and their associated failure rates adopted are presented in **Table 3.2**.

Table 3.2 Summary of Identified Failure Cases and Their Associated Failure Rates

Failure Cases	Failure Rates	Reference Source
Spontaneous Failure of Pressurised LPG Equipment		
Catastrophic Failure of Storage Vessel	1.8×10^{-7} per vessel year	Reference [2]
Partial Failure of Storage Vessel	5.0×10^{-6} per vessel year	Reference [2]
Catastrophic Failure of Road Tanker	2.0×10^{-6} per tanker year	Reference [2]
Partial Failure of Road Tanker	5.0×10^{-6} per tanker year	Reference [2]
Guillotine Failure of Pipework	1.0×10^{-6} per meter per year	Reference [2]
Hose Failure	9.0×10^{-8} per hour	Reference [2]
Dispenser Failure	4.38×10^{-2} per year	Refer to **Sections 3.4.1.6** to **3.4.1.7**
Vapour Return Line Failure	1.0×10^{-6} per meter per year	Reference [2]
Release from Storage Vessel Pump Flange	1.09×10^{-4} per year	Reference [10]
Release from Storage Vessel Drain Valve	2.0×10^{-5} per operation	Reference [11]
External Event		
Earthquake MMI VIII	1.0×10^{-5} per year	Reference [3]
Aircraft Crash	1.58×10^{-8} per year	Refer to **Sections 3.4.3.2** to **3.4.3.4**

Failure Cases	Failure Rates	Reference Source
LPG Loading Failure		
Hose Misconnection Failure	3.0×10^{-5} per operation	Reference [2]
Hose Disconnection Failure	2.0×10^{-6} per operation	Reference [2]
Tanker Drive-away Error	4.0×10^{-6} per operation	Reference [2]
Road Tanker Collision	1.5×10^{-4} per operation	Reference [2]
Vehicle Impact into Tanker During Unloading	1.0×10^{-8} per operation	Reference [2]
Storage Vessel Overfilling	2.0×10^{-2} per operation	Reference [2]
Safety Features Failure		
Pressure Relief Valve Failure	1.0×10^{-4} per demand	Reference [2] based on ESD system
Non-return Valve Failure	0.013 per demand	Reference [2]
Excess Flow Valve Failure	0.013 per demand for tanker 0.13 per demand for vessel	Reference [2]
Emergency Shutdown System Failure	1.0×10^{-4} per demand	Reference [2]
Double-check Filler Valve Failure	2.6×10^{-3} per demand	Reference [2]
Breakaway Coupling Failure	0.013 per demand for tanker 0.13 per demand for dispenser	Reference [2]
Manual Isolation Valve Failure	0.5 per demand	Reference [2]
Human Error		
Operator fails to rectify problem	0.2 per demand	Reference [3]
Fire Protection / Fighting System Failure		
Water Spray System Failure	1.5×10^{-2} per demand	Reference [2]
Failure of Fire Services	0.5 per demand	Reference [2]
Chartek Coating Failure	0.1	Reference [2]

3.4.7 Escalation

3.4.7.1 Escalation refers to the situation in which a relatively insignificant accident causing an event with much more significance to occur.

3.4.7.2 Typical hazards that could lead to escalation are:

(a) Shrapnel from LPG storage vessel impacting on an LPG road tanker;

(b) Ignited leak from above ground LPG facilities (jet fire) impinging an LPG road tanker and causing BLEVE; and

(c) Other fire incidents engulfing an LPG road tanker and causing BLEVE.

3.4.7.3 As the storage vessel will be installed underground, the knock-on failure on this equipment from other accidents is unlikely to occur. Therefore, knock-on failures on the storage vessel were not further considered.

3.4.7.4 When an LPG road tanker is impacted by the shrapnel from the LPG storage vessel (i.e. catastrophic rupture of vessels occurs), this is already a severe event and no knock-on events significantly worse have been identified.

BLEVE of LPG Road Tanker Caused by Jet Fire from Aboveground LPG Facilities

3.4.7.5 For a jet fire leading to BLEVE of LPG road tanker, the factors needed to be considered are as follows:

(a) Frequency of LPG leak from above ground LPG facilities last for at least 30 minutes

(b) Immediate ignition probability of LPG leak from above ground LPG facilities which causes a jet fire

(c) The portion of jet fire impinging at road tanker

(d) The portion of time for road tanker present in the GFS

(e) Failure to prevent BLEVE from occurring

3.4.7.6 The calculation of probability of road tanker BLEVE is shown in **Annex B**. The elaboration of the first three factors is provided below.

Frequency of LPG Leak from Aboveground LPG Facilities Lasting for at Least 30 Minutes

3.4.7.7 It was conservatively assumed that the inventory in the storage vessel at maximum inventory or 60% of maximum inventory would be enough to support a 30-minute leakage. On this basis, the frequencies of aboveground LPG facilities failure shown in **Annex B** were applied to the frequencies of LPG leak lasting for at least 30 minutes.

Immediate Ignition Probability of LPG Leak from Aboveground LPG Facilities

3.4.7.8 Immediate ignition of LPG release from aboveground LPG facilities will cause a jet fire. A probability of 0.05 was adopted in **Annex C** for immediate ignition of LPG leak from aboveground LPG facilities.

The Portion of Jet Fire Impinging at Road Tanker On Site

3.4.7.9 Not all the ignited jet fire from aboveground LPG facilities will impinge into the LPG road tanker. Jet fire due to LPG release from aboveground LPG facilities may impinge into other objects or burn as a free jet. A probability of 0.25 was assumed for the jet fire from most of the aboveground LPG facilities impinge into LPG road tanker on site by considering the relative angular position of the LPG road tanker to LPG facilities such as dispensers. For jet fire caused by liquid supply line between from road tanker and loading hose, probability of 0.5 was assumed.

3.4.7.10 By considering the five factors mentioned above, the calculated frequency of a jet fire from aboveground LPG facilities causing BLEVE of LPG road tanker is 4.14×10^{-9} per year.

BLEVE of LPG Road Tanker Caused by Other Fire Incidents

3.4.7.11 For a fire leading to BLEVE of the LPG road tanker, the factors needed to be considered are as follows:

(a) Frequency of fire incidents occurring in GFS

(b) The proportion of fire incidents severe enough to endanger the road tanker

(c) The portion of time for tanker present in the GFS

(d) Failure to prevent BLEVE from occurring

Frequency of Fire Incidents Occurring in GFS

3.4.7.12 The frequency is estimated by the following equation:

Number of fire incidents occurred / number of petrol filling station-year

3.4.7.13 Information on the number of fire incidents occurred was provided by the Hong Kong Fire Services Department. According to the record, there were 32 fire incidents occurred in petrol filling stations / LPG filling stations from the year of 1995 to 2018. Until 2007, there were 189 commercial petrol filling stations in Hong Kong. In 2011, there were 187 commercial petrol filling stations. The latest record as of December 2019 shows that there were 174 commercial petrol filling stations and 65 LPG filling stations. Assuming that the number of petrol filling stations/ LPG filling stations remained constant from 1995 to 2007, from 2008 to 2011 and from 2012 to 2019, the frequency of fire incidents is estimated as 6.56×10^{-3} fire incident per petrol filling station-year (i.e. 32 fire incidents / (189×13 + 187×4 + 239×7 petrol filling station-year).

3.4.7.14 It should be noted that this was a conservative estimate as all of the recorded fire incidents were assumed to be vehicle fire occurred in LPG filling stations.

The Proportion of Fire Incidents Severe Enough to Endanger the Road Tanker

3.4.7.15 Not all the fire incidents recorded/occurred in LPG filling stations will endanger the road tanker. A portion of recorded fire incidents could be false alarms that lead to over-estimation of the fire incident frequency. Moreover, a fire leading to BLEVE of road tanker needs to be of a sufficiently long duration (i.e. 30 minutes). However, most of the fire incidents occurred is small in scale such as fire caused by smoking, small fire in the office of the filling stations etc. Based on the above, a proportion of 1 in 100 was assumed for severe fire incidents.

3.4.7.16 By considering the four factors mentioned above, the calculated frequency of a fire incident in a GFS causing BLEVE of LPG road tanker is 5.81×10^{-9} per year.

4. HAZARD OCCURRENCE

4.1 Introduction

4.1.1.1 Subsequent to the hazard identification and analysis in the previous section, the next step is to estimate the likelihoods of the various LPG release cases. There are combinations of hazard initiating events, as identified in the previous section, which would lead to an LPG release.

4.1.1.2 Fault Tree Analysis (FTA) permits the hazardous incident ("Significant Failure Events") frequency to be estimated from a logical model of the failure mechanisms of a system. The model is based on the combinations of failures of more basic components, safety systems and human errors. Station-specific circumstances (e.g. number of LPG tanker visit) were taken into account in the FTA.

4.1.1.3 FTA is the use of a combination of simple logic gates, "AND" and "OR" gates, to synthesise a failure model of the hazardous installation. The "Significant Failure Events" frequency is calculated from failure data of more simple events.

4.1.1.4 A basic assumption in FTA is that all failures in a system are binary in nature, a component or operator either performs successfully or fails completely. In addition, the system is assumed to be functioning if all sub-components are operating properly.

4.1.1.5 The steps for an FTA are presented below:

- Hazard identification and selection of the "Significant Failure Events", where the "Significant Failure Events" are considered as significant LPG release cases;
- Construction of fault trees; and
- Quantitative evaluation of the fault trees.

4.2 Frequency of Occurrence

4.2.1.1 The fault tree diagrams are provided in **Annex B**, while the estimated likelihoods of various releases of LPG at the GFS are summarised in **Table 4.1**.

Table 4.1 Estimated Occurrence Frequency of Significant LPG Releases

Release Case	Frequency of Occurrence / Year
Catastrophic Failure of a Storage Vessel (Full Inventory)	1.27E-07
Catastrophic Failure of a Storage Vessel (60% Inventory)	2.97E-07
Catastrophic Failure of Road Tanker (Full Inventory)	4.77E-08
Catastrophic Failure of Road Tanker (50% Inventory)	1.91E-07
Partial Failure of a Storage Vessel (Full Inventory)	3.02E-06
Partial Failure of a Storage Vessel (60% Inventory)	7.05E-06
Partial Failure of Road Tanker (Full Inventory)	1.19E-07
Partial Failure of Road Tanker (50% Inventory)	4.77E-07
Guillotine Failure of Liquid Filling Line to Storage Vessel – release from vessel (Full Inventory in Storage Vessel)	2.85E-11
Guillotine Failure of Liquid Filling Line to Storage Vessel – release from vessel (60% Inventory in Storage Vessel)	6.65E-11
Guillotine Failure of Liquid Filling Line to Storage Vessel – release from road tanker (Full Inventory in Road Tanker)	2.24E-12

Release Case	Frequency of Occurrence / Year
Guillotine Failure of Liquid Filling Line to Storage Vessel – release from road tanker (50% Inventory in Road Tanker)	8.97E-12
Guillotine Failure of Liquid Filling Line to Dispenser (Full Inventory in Storage Vessel)	1.58E-07
Guillotine Failure of Liquid Filling Line to Dispenser (60% Inventory in Storage Vessel)	3.70E-07
Failure of Dispenser (Full Inventory in Storage Vessel)	1.11E-03
Failure of Dispenser (60% Inventory in Storage Vessel)	2.58E-03
Guillotine Failure of Hose during Unloading from Road Tanker to Storage Vessel, LPG Released from Tanker (Full Inventory in tanker)	6.23E-07
Guillotine Failure of Hose during Unloading from Road Tanker to Storage Vessel, LPG Released from Tanker (50% Inventory in tanker)	2.49E-06
Guillotine Failure of Hose during Unloading from Road Tanker to Storage Vessel, LPG Released from Vessel (Full Inventory in vessel)	2.43E-09
Guillotine Failure of Hose during Unloading from Road Tanker to Storage Vessel, LPG Released from Vessel (60% Inventory in vessel)	5.67E-09
Failure of Flexible Hose during Loading to LPG vehicles, LPG Released from Dispenser (Full Inventory in Storage Vessel)	1.41E-01
Failure of Flexible Hose during Loading to LPG vehicles, LPG Released from Dispenser (60% Inventory in Storage Vessel)	3.29E-01
Failure of Flexible Hose during Loading to LPG vehicles, LPG Released from vehicle (Full Inventory in Vehicle)	9.40E-01
Release from Storage Vessel Pump Flange (Full Inventory in Storage Vessel)	1.31E-04
Release from Storage Vessel Pump Flange (60% Inventory in Storage Vessel)	3.05E-04
Release from Storage Vessel Drain Valve (Full Inventory in Storage Vessel)	1.44E-04
Release from Storage Vessel Drain Valve (60% Inventory in Storage Vessel)	3.36E-04
Failure of Vapour Return Line (Full Inventory in Storage Vessel)	2.30E-07
Failure of Vapour Return Line (60% Inventory in Storage Vessel)	5.36E-07
Guillotine Failure of Liquid Line from Tanker to Flexible Hose (full inventory in Road Tanker)	1.82E-09
Guillotine Failure of Liquid Line from Tanker to Flexible Hose (50% inventory in Road Tanker)	7.26E-09
BLEVE of Road Tanker (Full Inventory in Road Tanker)	1.99E-09
BLEVE of Road Tanker (50% Inventory in Road Tanker)	7.96E-09

5. CONSEQUENCE AND IMPACT ANALYSIS

5.1 Introduction

5.1.1.1 Consequence and impact analysis were conducted to provide a quantitative estimate of the likelihood and number of deaths associated with the range of possible outcomes (i.e. fireball, jet fire, flash fire etc.) which would result from the failure cases identified in the previous sections. Releases from hazardous sources and their consequences were modelled using SAFETI 8.7.

5.2 Modelling Input

5.2.1.1 Failure events identified in the previous sections were considered and evaluated through consequence analysis. The failure events with potential off-site impacts are considered as follows:

(a) Rupture of storage vessel

(b) Rupture of road tanker

(c) Partial failure of storage vessel

(d) Partial failure of road tanker

(e) Guillotine failure of liquid filling line to storage vessel

(f) Pump flange leak

(g) BLEVE of road tanker

5.2.1.2 There will be two underground vessels with capacity of 25.4kL (water capacity) at the GFS. The storage vessels were assumed to be filled to a maximum permissible level (85% of the maximum capacity). Replenishment of LPG was assumed to be 730 deliveries per year, which can be arranged either daytime or night-time.

5.3 Ignition Source

5.3.1 General

5.3.1.1 To calculate the risk from flammable materials, information on ignition sources presented in the study area needs to be identified. Such data was included in the risk model for each type of ignition source (i.e. point sources, line sources and area sources). The risk calculation program (MPACT) in SAFETI predicts the probability of a flammable cloud being ignited (delayed ignition) as the cloud moves downwind over ignition sources.

5.3.2 Point Source

5.3.2.1 According to HSE (1997) [13], compressors could be categorised as a strong ignition source with an ignition probability greater than 0.5 but smaller than 1. Although a vehicle using the GFS is located close to a release source, it is classified as a weak ignition source with ignition probability between 0.05 and 0.5. Therefore, the following assumptions were applied to estimate the presence factor of the point source and the ignition probability.

(a) Probability of ignition for a compressor is taken as 0.75 in 60 seconds; and

(b) Presence factor of the ignition source is assumed to be 1.

5.3.3 Line Source

5.3.3.1 Roads are defined as line sources in SAFETI. The following assumptions were applied to estimate the presence factor of the line source and the ignition probability:

(a) The probability of ignition for a vehicle was taken to be 0.4 in 60 seconds [6]; and

(b) The traffic density was based on the projected traffic flow adopted for population estimation as detailed in **Annex A**.

5.3.3.2 Ignition line sources are summarized in **Table 5.1**.

Table 5.1 Summary of Road Ignition Sources

ID	Description	Traffic Speed (km/hr)	Traffic Density (veh/hr)			
			Year 2035		Year 2041	
			Daytime	Night-time	Daytime	Night-time
R01	Road L8	50	564	271	517	244
R02		50	593	257	556	237
R03		50	315	145	330	147
R04		50	311	144	336	151
R05	Road L7	50	321	132	230	92
R06		50	290	149	203	103
R07	Road L1	50	-	-	184	97
R08		50	-	-	189	99
R09		50	-	-	172	90
R10		50	-	-	172	90

5.3.4 Area Source

5.3.4.1 SAFETI considers a residential population as an ignition source (as a result of activities such as cooking, smoking, heating appliances etc.). The ignition probability was derived from the population densities in the concerned area by SAFETI.

5.4 Ignition Probability

5.4.1.1 Immediate ignition probabilities of 0.9 and 0.05 [2] were adopted for instantaneous release and continuous release of LPG, respectively. These ignition probabilities were applied to event trees as shown in **Annex C**.

5.5 Protection Factors

5.5.1.1 With reference to previous practice of assessments with SAFETI in Hong Kong, protection factors were considered and applied to the concerned population groups if applicable.

5.5.2 Protection afforded to persons indoors in a building

5.5.2.1 It was generally assumed that the respective outdoor/ indoor population are 5% and 95% at the time of an accident [2].

5.5.2.2 For flash fire consequence, the fatality rate for indoor persons was assumed to be one tenth of the outdoor fatality rate.

5.5.2.3 For fireball, it was assumed that 50% of indoor persons would be killed.

5.5.3 Protection afforded to persons by being on the upper floors of building

5.5.3.1 Cloud height decreases further away from the source. Most dispersed clouds for LPG will have a cloud height lower than 10m [2]. To be conservative, no height protection factor was applied in this QRA.

6. RISK EVALUATION

6.1 Introduction

6.1.1.1 In this section, the risks arising from the LPG facilities were evaluated in terms of both individual and societal risks.

6.1.1.2 Individual risk is a measure of the risk to a chosen individual at a particular location. As such, this is evaluated by summing the contributions to that risk across a spectrum of incidents that could occur at a particular location.

6.1.1.3 Societal risk is a measure of the overall impact of an activity upon the surrounding community. As such, the likelihoods and consequences of the range of incidents postulated for that particular activity are combined to create a cumulative picture of the spectrum of the possible consequences and their frequencies. This is usually presented in the form of a FN curve and the acceptability of the results can be assessed against the societal risk criterion under the HKRG.

6.2 Individual Risk

6.2.1 Risk Level

6.2.1.1 The predicted individual risk (IR) levels associated with operation of the GFS are shown in **Plate 6.1**. The risk levels were estimated based on 100% occupancy with no allowance made for shelter or escape, as specified in the user manual of SAFETI. The HKRG criterion for individual risk is that no person off-site should be subject to an additional risk of 1×10^{-5} per year.

6.2.2 Acceptability

6.2.3 The maximum individual risk of less than 1×10^{-5} per year is observed from the figure. Given that there is no off-site risk with frequency greater than 1×10^{-5} per year, the level of individual risk posed by the operation of the GFS to the surrounding population is considered acceptable and in compliance with the HKRG.

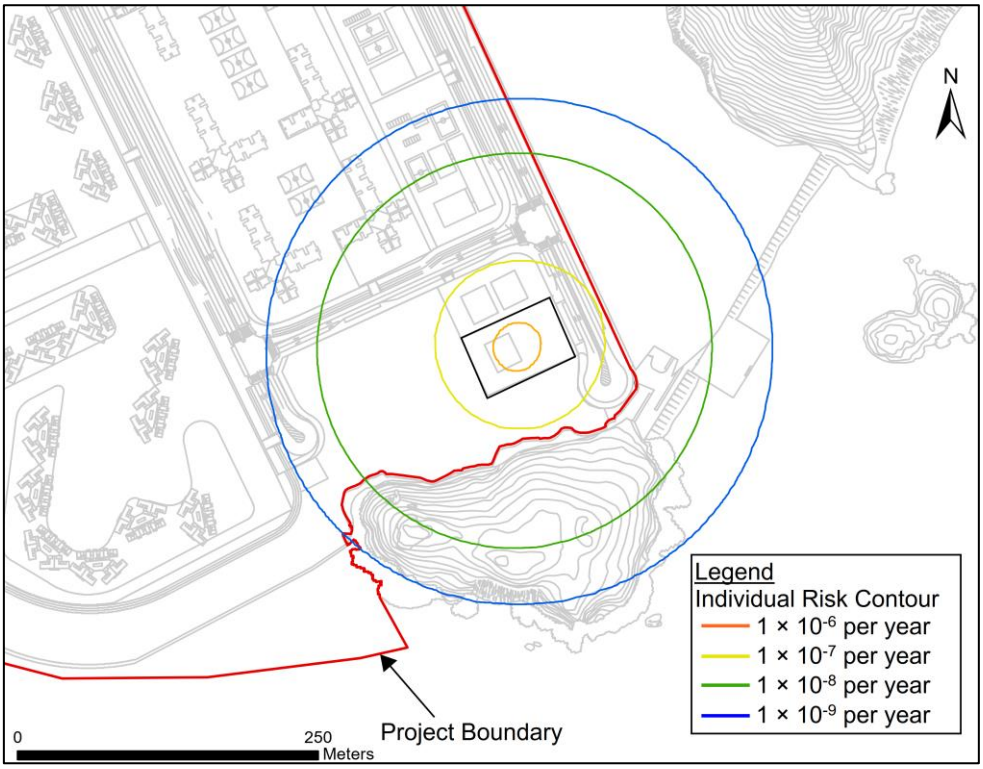

Plate 6.1 Individual Risk Contours for the GFS

6.3 Societal Risk

6.3.1 Risk Level

6.3.1.1 The expression of the level of societal risk is more complex than that for individual risk but, in essence, comprises three regions:

(a) "Unacceptable" – a region within which the risks may be regarded as unacceptable;

(b) "Acceptable" – a region within which the risks may be regarded as acceptable; and

(c) "ALARP" – a region between the two in which measures should be taken to demonstrate the risks as "as low as reasonably practicable" (ALARP). In other words, consideration is given not only to the level of risk but also the cost and practicality of reducing it.

6.3.2 Acceptability

6.3.2.1 The FN curves associated with the operation of the GFS are plotted against the HKRG risk guideline and presented in **Plate 6.2**. As observed, the societal risks fall within the "Acceptable" region in both assessment years, and therefore the associated societal risk is considered acceptable.

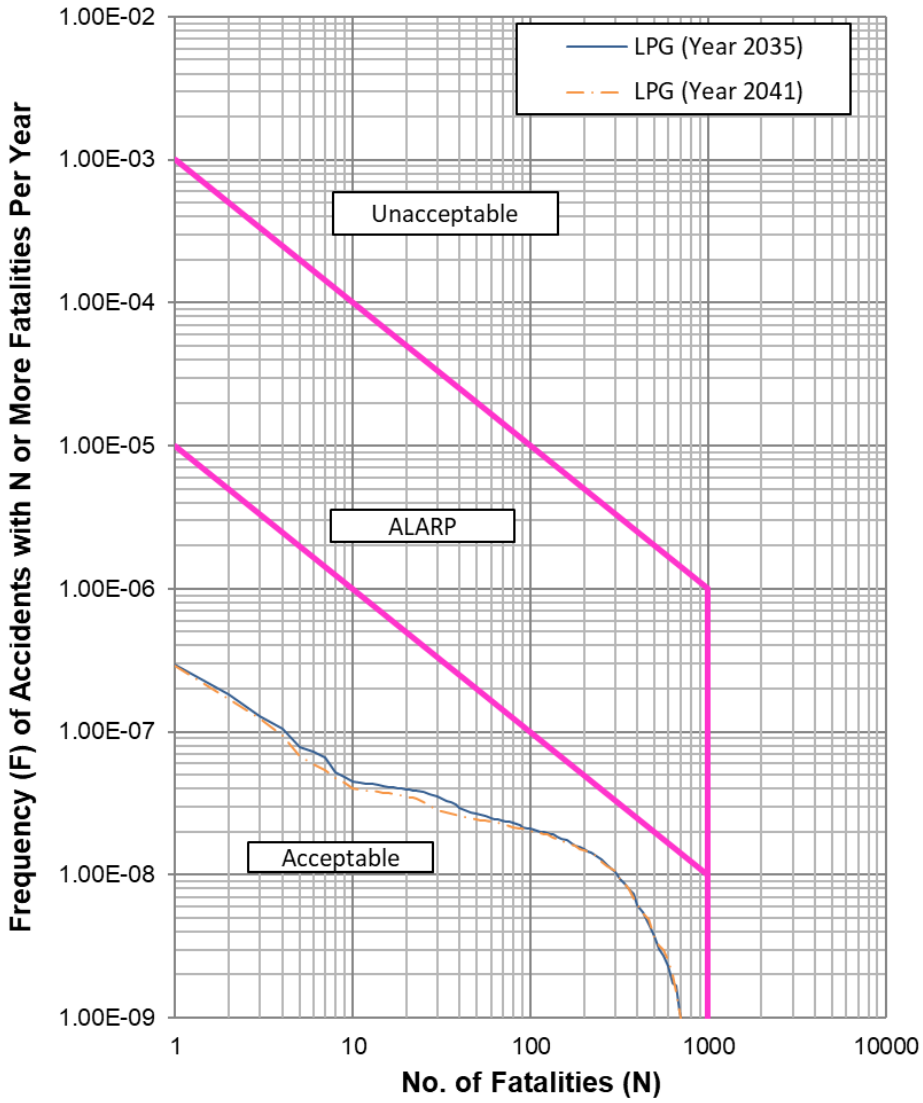

Plate 6.2 Societal Risk Curves

6.3.3 Potential Loss of Life (PLL)

6.3.3.1 The total PLL and top five most significant risk contributing events for the assessed scenarios are tabulated in **Table 6.1**. The total PLL was found to be about 8.6×10^{-6} per year and 8.2×10^{-6} per year for Year 2035 and Year 2041 respectively. For both assessed scenarios, cold catastrophic failure of storage vessel was found to be the major contributor to the overall risk.

Table 6.1 Breakdown of PLL (All Assessed Scenarios)

Event Description	Year 2035 (Construction Phase)		Year 2041 (Operation Phase)	
	PLL (per year)	PLL (%)	PLL (per year)	PLL (%)
Catastrophic Failure of a Storage Vessel (60% Inventory)	3.49E-06	40.8	3.35E-06	40.8
Catastrophic Failure of a Storage Vessel (Full Inventory)	3.14E-06	36.7	3.10E-06	37.8

Event Description	Year 2035 (Construction Phase)		Year 2041 (Operation Phase)	
	PLL (per year)	PLL (%)	PLL (per year)	PLL (%)
Catastrophic Failure of Road Tanker (Full Inventory)	8.35E-07	9.8	8.12E-07	9.9
Catastrophic Failure of Road Tanker (50% Inventory)	7.34E-07	8.6	6.46E-07	7.9
Partial Failure of Road Tanker (50% Inventory)	2.66E-07	3.1	2.22E-07	2.7
Others	9.07E-08	1.1	7.82E-08	1.0
Total	**8.55E-06**	**100**	**8.21E-06**	**100**

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

7.1.1.1 A full QRA was carried out for the green fuel station, which is proposed to provide LPG filling services within the project site. The assessment was conducted based on LPG throughput estimates by the Consultant, and also information collected from Census and Statistics Department, Hong Kong Observatory, Planning Department and Transport Department.

7.1.1.2 The predicted individual risks for the GFS comply with the HKRG as stipulated in HKPSG with no off-site population subject to individual risk levels exceeding the criterion of 1×10^{-5} per year. The predicted societal risks for the GFS also fall into the “Acceptable” region. Therefore, no mitigation measure is required. The assessment concludes that the operation of the green fuel station would not result in unacceptable risks to the overall population around the station.

7.2 Recommendations

7.2.1.1 The level of individual and societal risks for the proposed green fuel station would be acceptable on risk grounds based on the information and data available at the time of preparing this report.

7.2.1.2 The future land uses, in particular those associated with significant population increase when compared with those assumed in this assessment, in the vicinity of the proposed GFS should be carefully assessed using QRA to ensure that the risk levels to any new population are acceptable. In addition, the QRA should be reviewed and updated when the LPG delivery frequency and throughput exceeds those specified in the assessment as a significant increase in the throughput of the GFS and/or the number of LPG road tanker deliveries would also increase the risk outcomes.

8. REFERENCES

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Annex A

Population Data

Annex A - Population Data

Table A1 - Surrounding Population Estimates

ID	Population Group	Land_ID	Land Use Zoning	Maximum Population (Year 2035)	Maximum Population (Year 2041)	Indoor Ratio	% of Occupancy				Population (Year 2035)				Population (Year 2041)			
							Weekday Day	Weekday Night	Weekend Day	Weekend Night	Weekday Day	Weekday Night	Weekend Day	Weekend Night	Weekday Day	Weekday Night	Weekend Day	Weekend Night
P01	Secondary School	E5	E	2412	2412	0.95	1	0	0.5	0	2412	0	1206	0	2412	0	1206	0
P02	Public Housing (PU6)																	
P02a	Block 3	PU6	RSc	3230	3230	0.95	0.5	1	0.7	1	1615	3230	2261	3230	1615	3230	2261	3230
P02b	Block 5	PU6	RSc	3230	3230	0.95	0.5	1	0.7	1	1615	3230	2261	3230	1615	3230	2261	3230
P02c	Block 6	PU6	RSc	3230	3230	0.95	0.5	1	0.7	1	1615	3230	2261	3230	1615	3230	2261	3230
P02d	Podium 1	PU6	RSc	2452	2452	0.95	1	0.1	1	0.1	2452	245	2452	245	2452	245	2452	245
P03	132kV Primary ESS	OU2	OU	0	0	0.95	1	1	1	1	0	0	0	0	0	0	0	0
P04	Proposed Project Works Areas (PR5)	PR5	-	150	-	0	1	0.1	0.5	0.1	150	15	75	15	-	-	-	-
P05	Proposed Project Works Areas (Road L1)	Road	-	150	-	0	1	0.1	0.5	0.1	150	15	75	15	-	-	-	-
P06	Explosives Off-loading Pier	-	-	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
P07	Desalination Plant	-	OU	160	160	0	1	0.1	0.5	0.1	160	16	80	16	160	16	80	16
R01	Road L8	Road	Road	18	10	0	-	-	-	-	18	13	18	13	10	9	10	9
R02	Road L8	Road	Road	17	12	0	-	-	-	-	17	12	17	12	12	10	12	10
R03	Road L8	Road	Road	7	7	0	-	-	-	-	7	7	7	7	7	7	7	7
R04	Road L8	Road	Road	7	7	0	-	-	-	-	7	7	7	7	7	7	7	7
R05	Road L7	Road	Road	26	13	0	-	-	-	-	26	17	26	17	13	11	13	11
R06	Road L7	Road	Road	27	11	0	-	-	-	-	27	19	27	19	11	10	11	10
R07	Road L1	Road	Road	-	9	0	-	-	-	-	-	-	-	-	9	9	9	9
R08	Road L1	Road	Road	-	9	0	-	-	-	-	-	-	-	-	9	9	9	9
R09	Road L1	Road	Road	-	7	0	-	-	-	-	-	-	-	-	7	7	7	7
R10	Road L1	Road	Road	-	7	0	-	-	-	-	-	-	-	-	7	7	7	7

Annex A - Population Data

Table A2 - Road Population

Daytime Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R01 - Road L8													
Total Vehicle per hour	0.2	50	14	240	76	8	0	88	51	9	2	75	564
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	2	1	1	0	1	1	1	0	10	18
Person (%)	-		6%	11%	6%	6%	0%	6%	6%	6%	0%	56%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R02 - Road L8													
Total Vehicle per hour	0.2	50	16	261	86	9	0	86	50	10	2	72	593
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	2	1	1	0	1	1	1	0	9	17
Person (%)	-		6%	12%	6%	6%	0%	6%	6%	6%	0%	53%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R03 - Road L8													
Total Vehicle per hour	0.1	50	10	165	54	6	0	51	24	6	0	0	315
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R04 - Road L8													
Total Vehicle per hour	0.1	50	10	165	54	6	0	48	22	6	0	0	311
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R05 - Road L7													
Total Vehicle per hour	0.3	50	6	95	33	4	0	37	32	4	3	108	321
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	19	26
Person (%)	-		4%	4%	4%	4%	0%	4%	4%	4%	0%	73%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R06 - Road L7													
Total Vehicle per hour	0.3	50	4	74	22	2	0	36	32	3	3	112	290
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	20	27
Person (%)	-		4%	4%	4%	4%	0%	4%	4%	4%	0%	74%	100%

Note:
[1] Person per vehicle is based on the occupancy in Year 2022 from Station 5021 (Tseung Kwan O Tunnel (from Toll Plaza to Tseung Kwan O Tunnel Rd RA)) from Transport Department - The Annual Traffic Census 2022.

Night-time Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R01 - Road L8													
Total Vehicle per hour	0.2	50	7	128	59	2	0	22	6	3	1	44	271
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	6	13
Person (%)	-		8%	8%	8%	8%	0%	8%	8%	8%	0%	46%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R02 - Road L8													
Total Vehicle per hour	0.2	50	8	122	55	3	0	21	6	4	1	38	257
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	5	12
Person (%)	-		8%	8%	8%	8%	0%	8%	8%	8%	0%	42%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R03 - Road L8													
Total Vehicle per hour	0.1	50	5	82	38	2	0	13	3	2	0	0	145
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R04 - Road L8													
Total Vehicle per hour	0.1	50	5	82	38	2	0	12	3	2	0	0	144
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R05 - Road L7													
Total Vehicle per hour	0.3	50	3	39	17	2	0	9	2	2	1	57	132
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	10	17
Person (%)	-		6%	6%	6%	6%	0%	6%	6%	6%	0%	59%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2035 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R06 - Road L7													
Total Vehicle per hour	0.3	50	2	45	21	0	0	9	2	1	1	66	149
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	12	19
Person (%)	-		5%	5%	5%	5%	0%	5%	5%	5%	0%	63%	100%

Note:
[1] Person per vehicle is based on the occupancy in Year 2022 from Station 5021 (Tseung Kwan O Tunnel (from Toll Plaza to Tseung Kwan O Tunnel Rd RA)) from Transport Department - The Annual Traffic Census 2022.

Annex A - Population Data

Table A2 - Road Population

Daytime Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R01 - Road L8													
Total Vehicle per hour	0.2	50	15	249	79	8	3	100	47	9	0	8	517
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	2	1	1	1	1	1	1	0	1	10
Person (%)	-		10%	20%	10%	10%	10%	10%	10%	10%	0%	10%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R02 - Road L8													
Total Vehicle per hour	0.2	50	16	263	87	9	4	101	47	10	0	19	556
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	2	1	1	1	1	1	1	0	3	12
Person (%)	-		8%	17%	8%	8%	8%	8%	8%	8%	0%	25%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R03 - Road L8													
Total Vehicle per hour	0.1	50	10	163	53	6	0	63	29	6	0	0	330
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R04 - Road L8													
Total Vehicle per hour	0.1	50	10	168	54	6	0	63	29	6	0	0	336
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R05 - Road L7													
Total Vehicle per hour	0.3	50	6	95	33	4	6	37	17	4	1	29	230
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	5	13
Person (%)	-		8%	8%	8%	8%	8%	8%	8%	8%	0%	38%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R06 - Road L7													
Total Vehicle per hour	0.3	50	5	87	26	3	4	42	20	3	0	12	203
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	3	11
Person (%)	-		9%	9%	9%	9%	9%	9%	9%	9%	0%	27%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R07 - Road L1													
Total Vehicle per hour	0.1	50	6	96	30	3	2	23	11	4	0	10	184
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	1	9
Person (%)	-		11%	11%	11%	11%	11%	11%	11%	11%	0%	11%	100%

Night-time Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R01 - Road L8													
Total Vehicle per hour	0.2	50	7	132	61	2	1	25	7	3	0	4	244
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	1	9
Person (%)	-		11%	11%	11%	11%	11%	11%	11%	11%	0%	11%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R02 - Road L8													
Total Vehicle per hour	0.2	50	8	123	55	3	2	25	7	4	0	11	237
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	2	10
Person (%)	-		10%	10%	10%	10%	10%	10%	10%	10%	0%	20%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R03 - Road L8													
Total Vehicle per hour	0.1	50	5	81	37	2	0	16	4	2	0	0	147
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R04 - Road L8													
Total Vehicle per hour	0.1	50	5	84	38	2	0	16	4	2	0	0	151
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R05 - Road L7													
Total Vehicle per hour	0.3	50	3	39	17	2	2	9	2	2	0	16	92
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	3	11
Person (%)	-		9%	9%	9%	9%	9%	9%	9%	9%	0%	27%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R06 - Road L7													
Total Vehicle per hour	0.3	50	3	53	25	0	2	11	3	1	0	7	103
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	2	10
Person (%)	-		10%	10%	10%	10%	10%	10%	10%	10%	0%	20%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R07 - Road L1													
Total Vehicle per hour	0.1	50	3	54	25	1	1	6	2	1	0	5	97
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	1	9
Person (%)	-		11%	11%	11%	11%	11%	11%	11%	11%	0%	11%	100%

Annex A - Population Data

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R08 - Road L1													
Total Vehicle per hour	0.1	50	6	102	32	3	1	25	12	4	0	4	189
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	1	9
Person (%)	-		11%	11%	11%	11%	11%	11%	11%	11%	0%	11%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R08 - Road L1													
Total Vehicle per hour	0.1	50	3	57	27	1	1	6	2	1	0	2	99
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	1	9
Person (%)	-		11%	11%	11%	11%	11%	11%	11%	11%	0%	11%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R09 - Road L1													
Total Vehicle per hour	0.1	50	6	96	30	3	0	23	11	4	0	0	172
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R09 - Road L1													
Total Vehicle per hour	0.1	50	3	54	25	1	0	6	2	1	0	0	90
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R10 - Road L1													
Total Vehicle per hour	0.1	50	6	96	30	3	0	23	11	4	0	0	172
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041 with Project)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R10 - Road L1													
Total Vehicle per hour	0.1	50	3	54	25	1	0	6	2	1	0	0	90
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

Note:
[1] Person per vehicle is based on the occupancy in Year 2022 from Station 5021 (Tseung Kwan O Tunnel (from Toll Plaza to Tseung Kwan O Tunnel Rd RA)) from Transport Department - The Annual Traffic Census 2022.

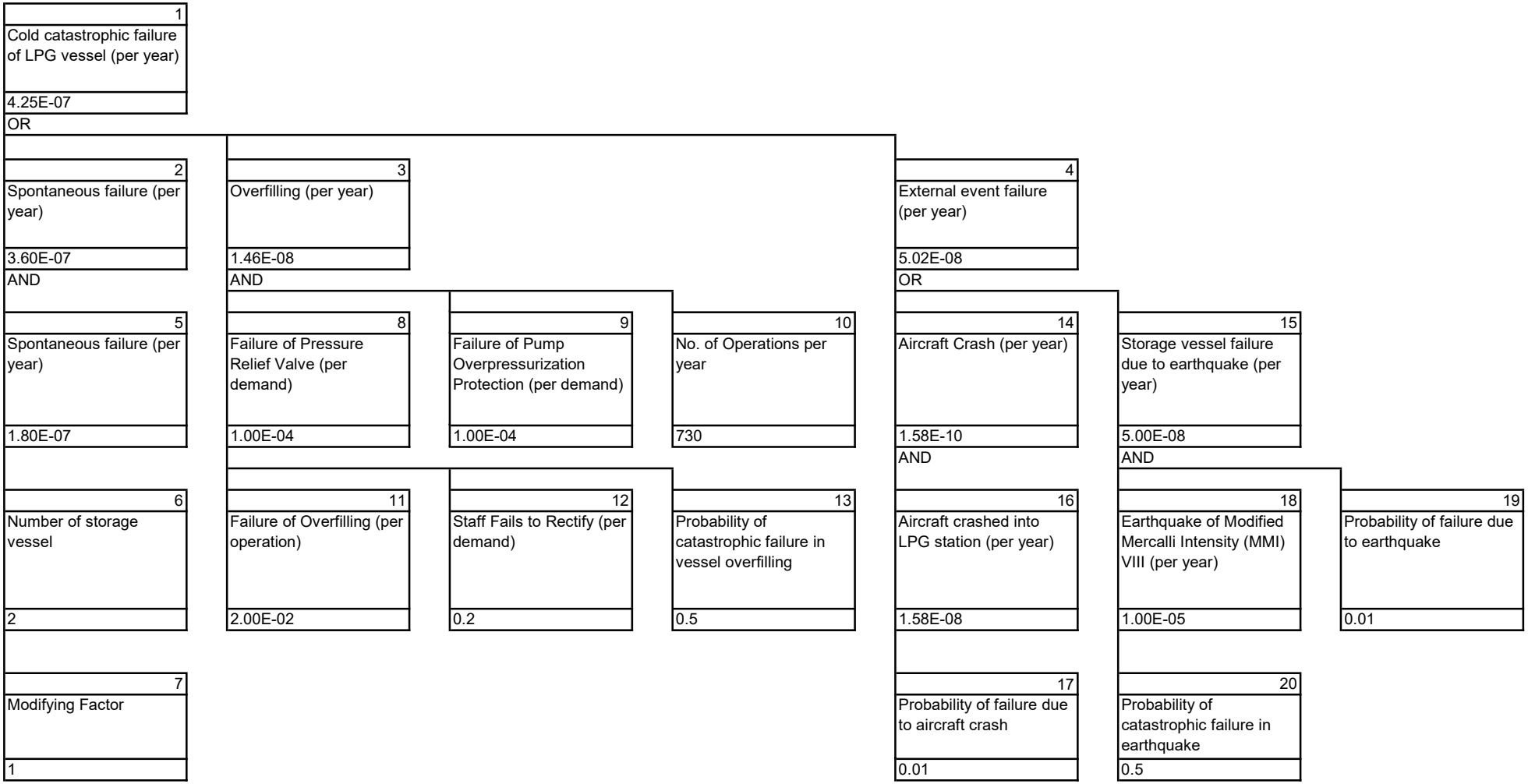
Note:
[1] Person per vehicle is based on the occupancy in Year 2022 from Station 5021 (Tseung Kwan O Tunnel (from Toll Plaza to Tseung Kwan O Tunnel Rd RA)) from Transport Department - The Annual Traffic Census 2022.

Annex B

Fault Tree Analysis

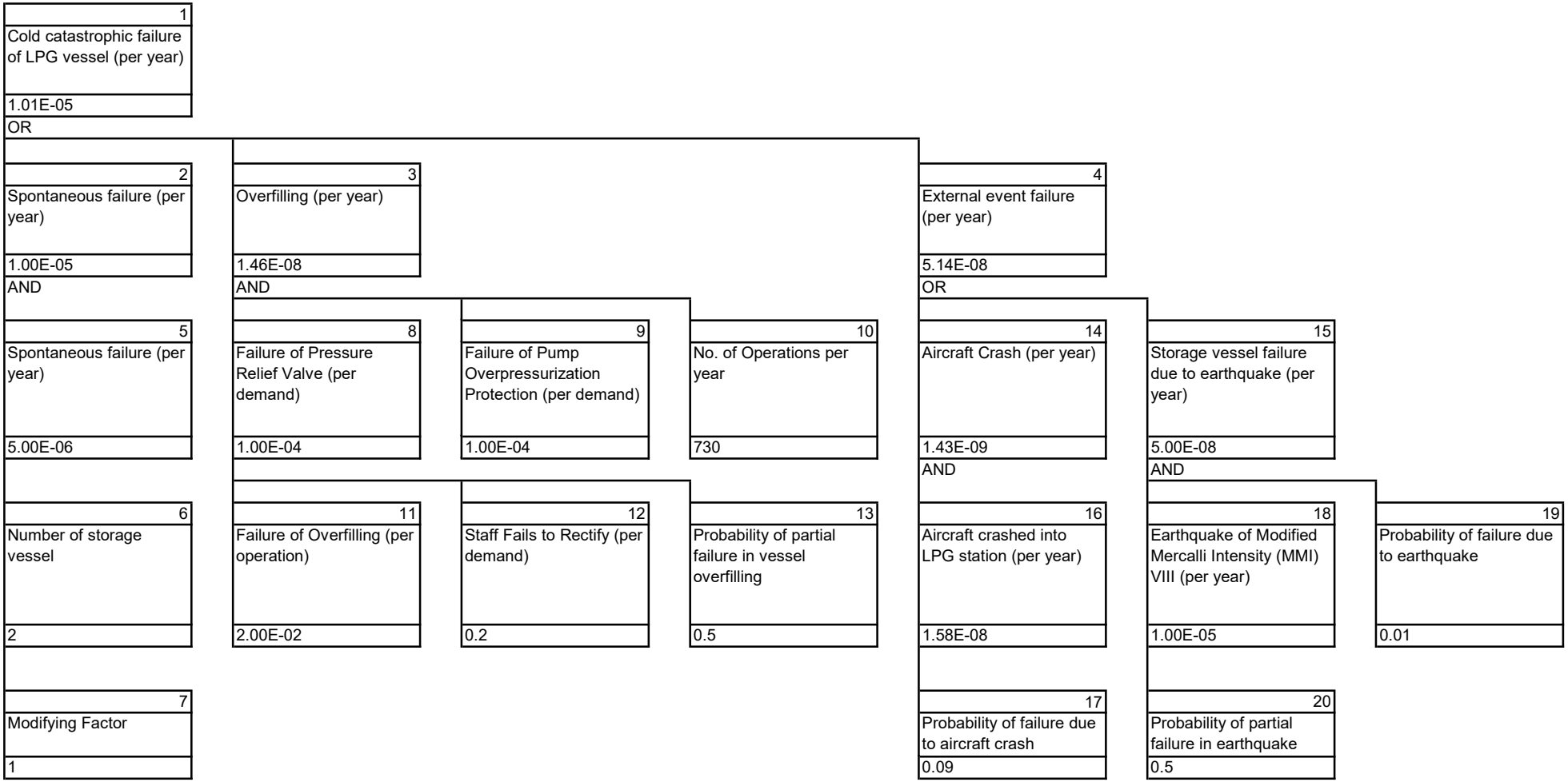
Annex B - Fault Tree Analysis

A-1 ***Cold Catastrophic Failure of an LPG Vessel***



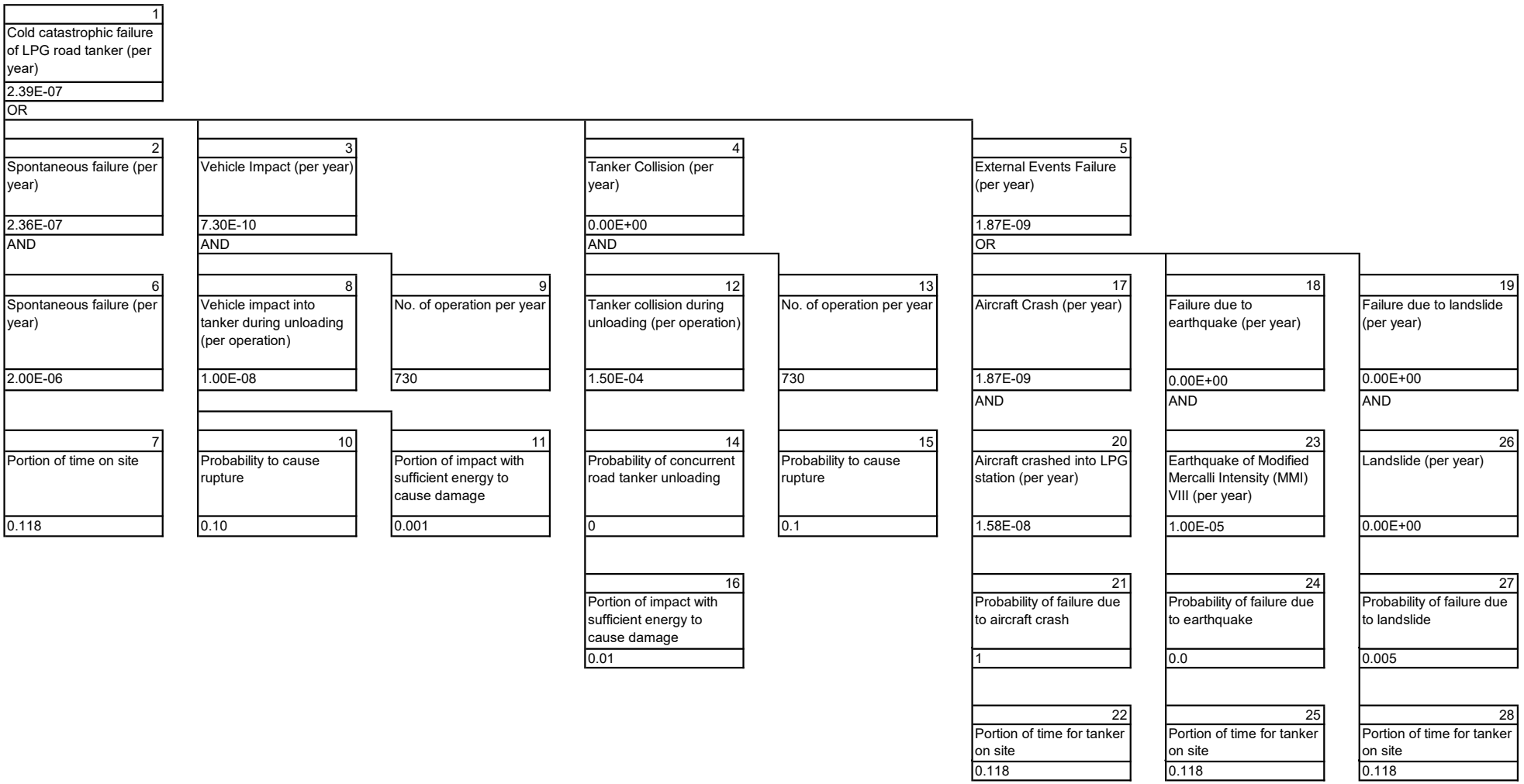
Annex B - Fault Tree Analysis

A-2 ***Cold Partial Failure of an LPG Vessel***



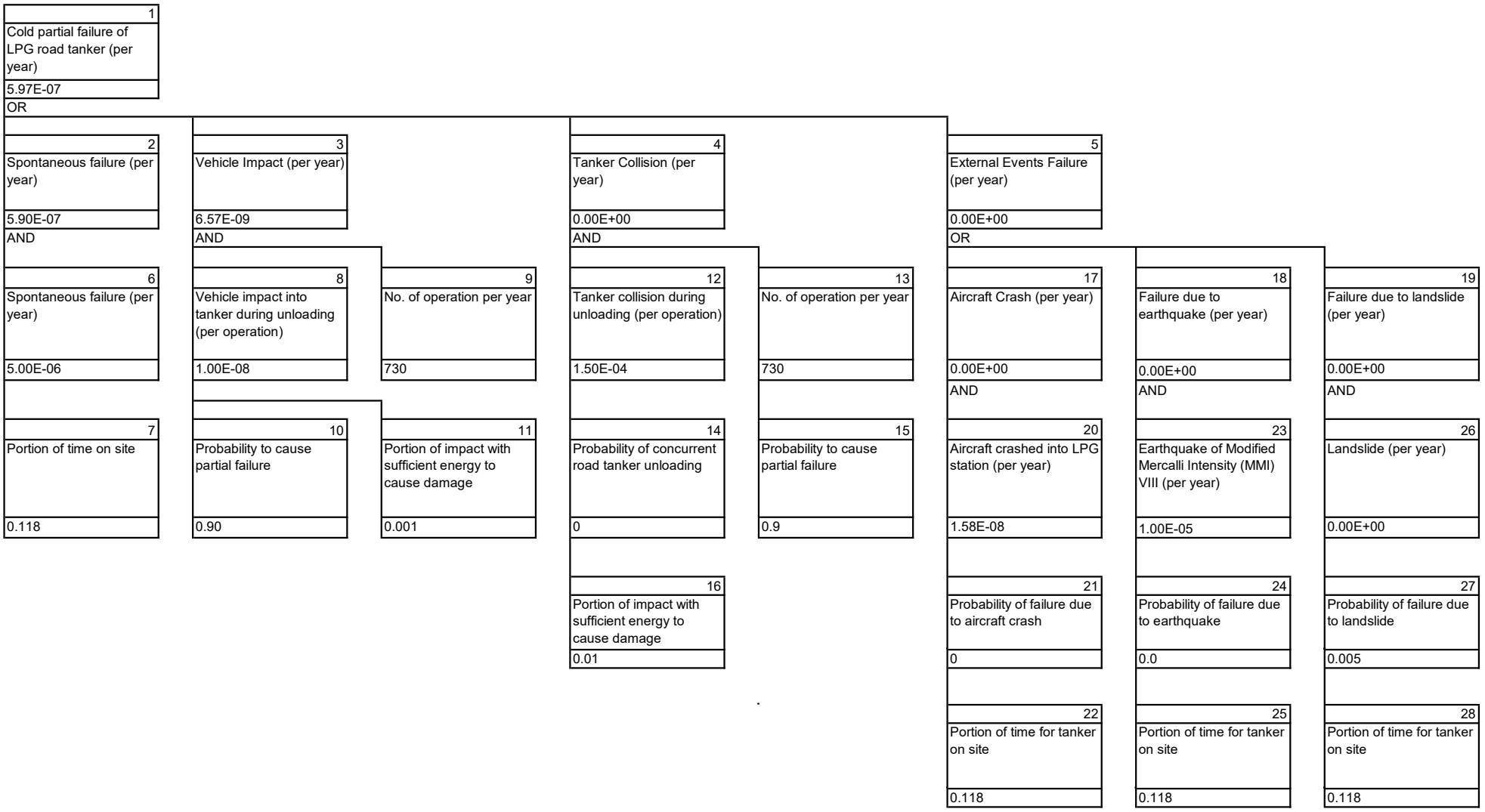
Annex B - Fault Tree Analysis

A-3 ***Cold Catastrophic Failure of Road Tanker***



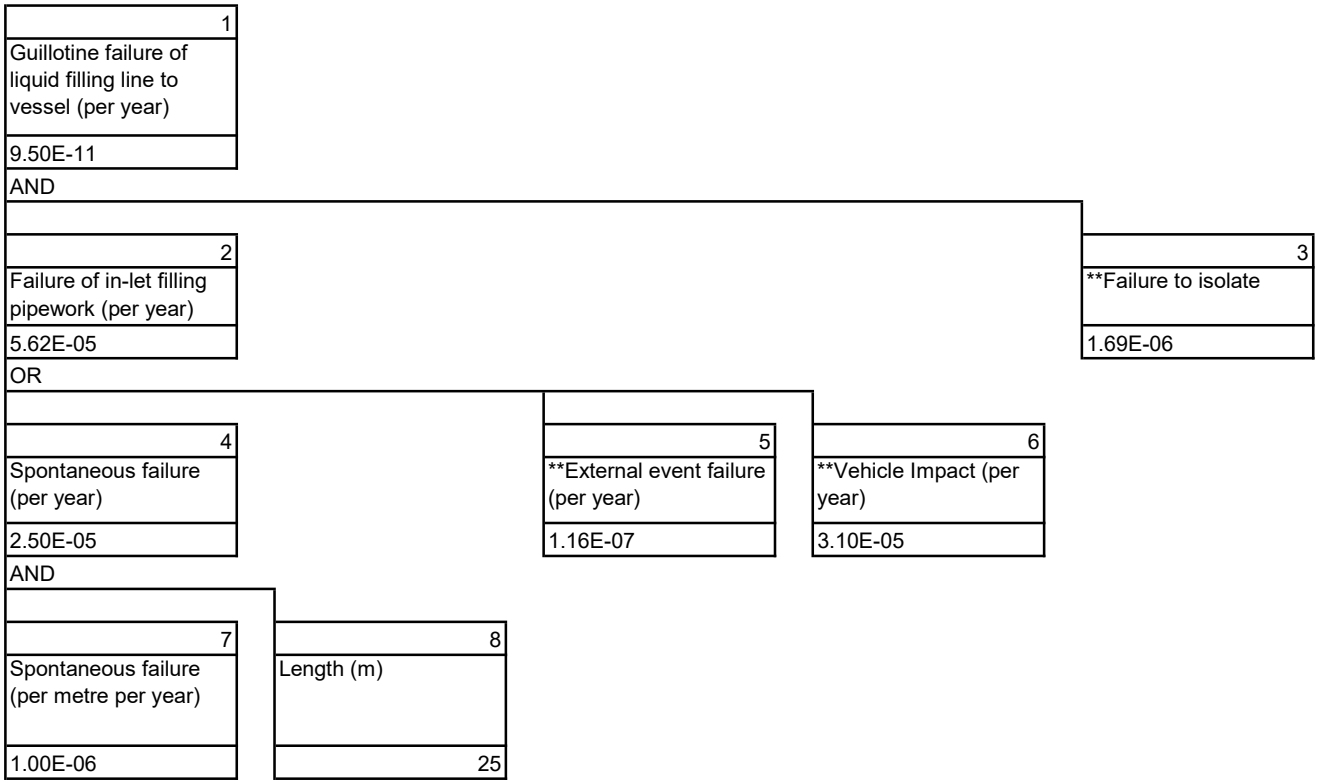
Annex B - Fault Tree Analysis

A-4 ***Cold Partial Failure of Road Tanker***



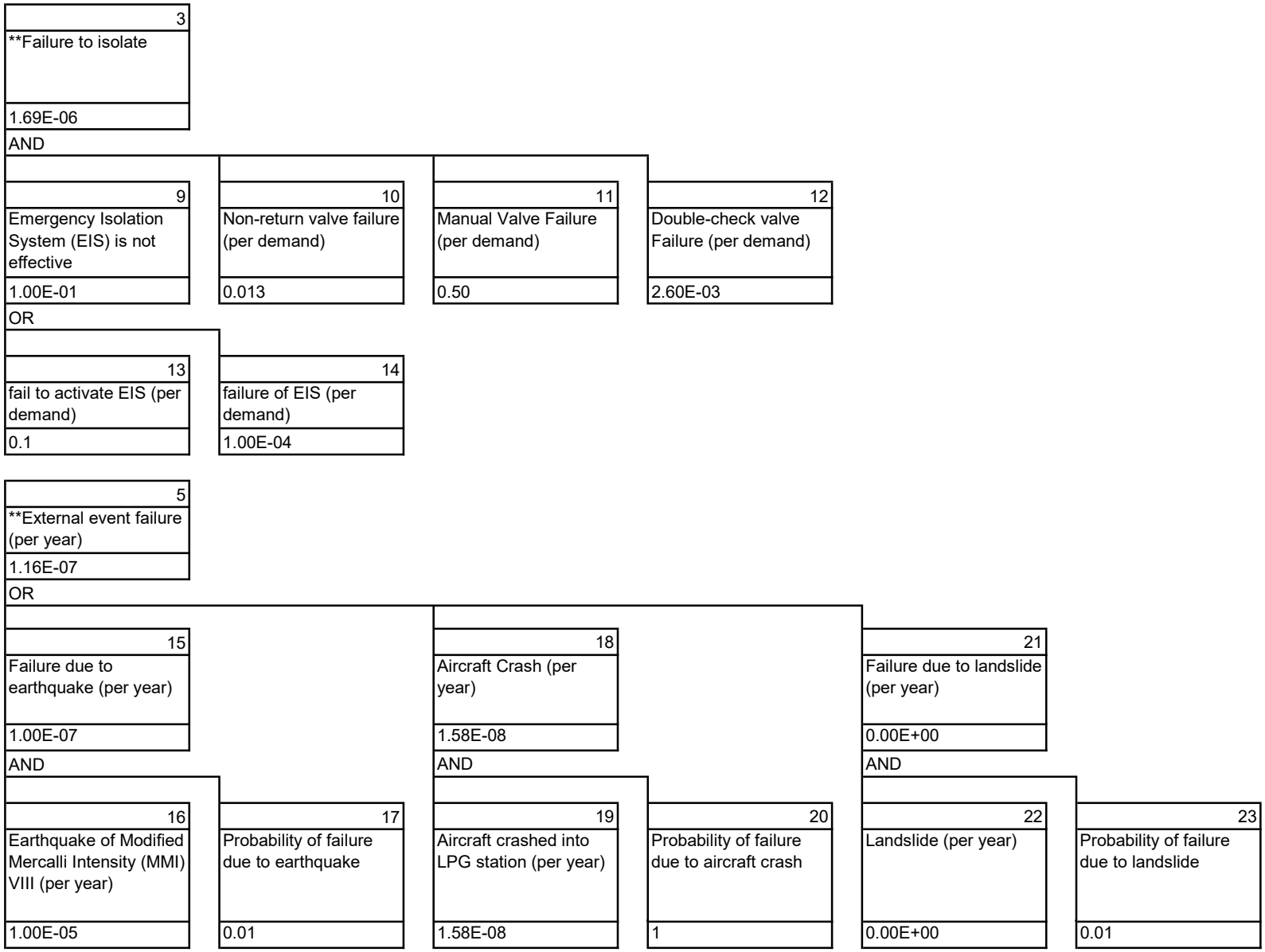
Annex B - Fault Tree Analysis

A-5a ***Guillotine Failure of In-let Filling Pipework (release from the vessel)***



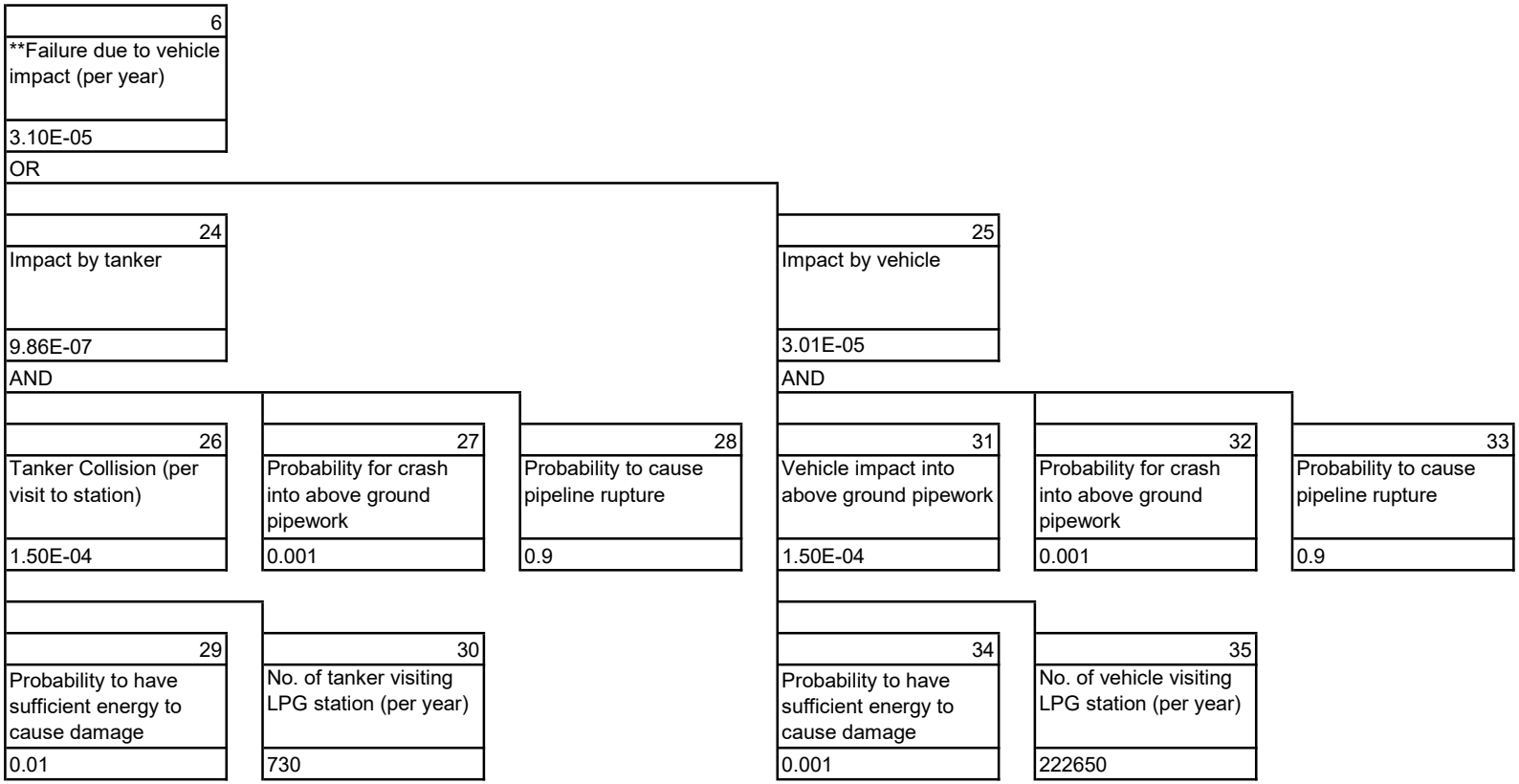
Annex B - Fault Tree Analysis

A-5a ***Guillotine Failure of In-let Filling Pipework (release from the vessel) (Con't)***



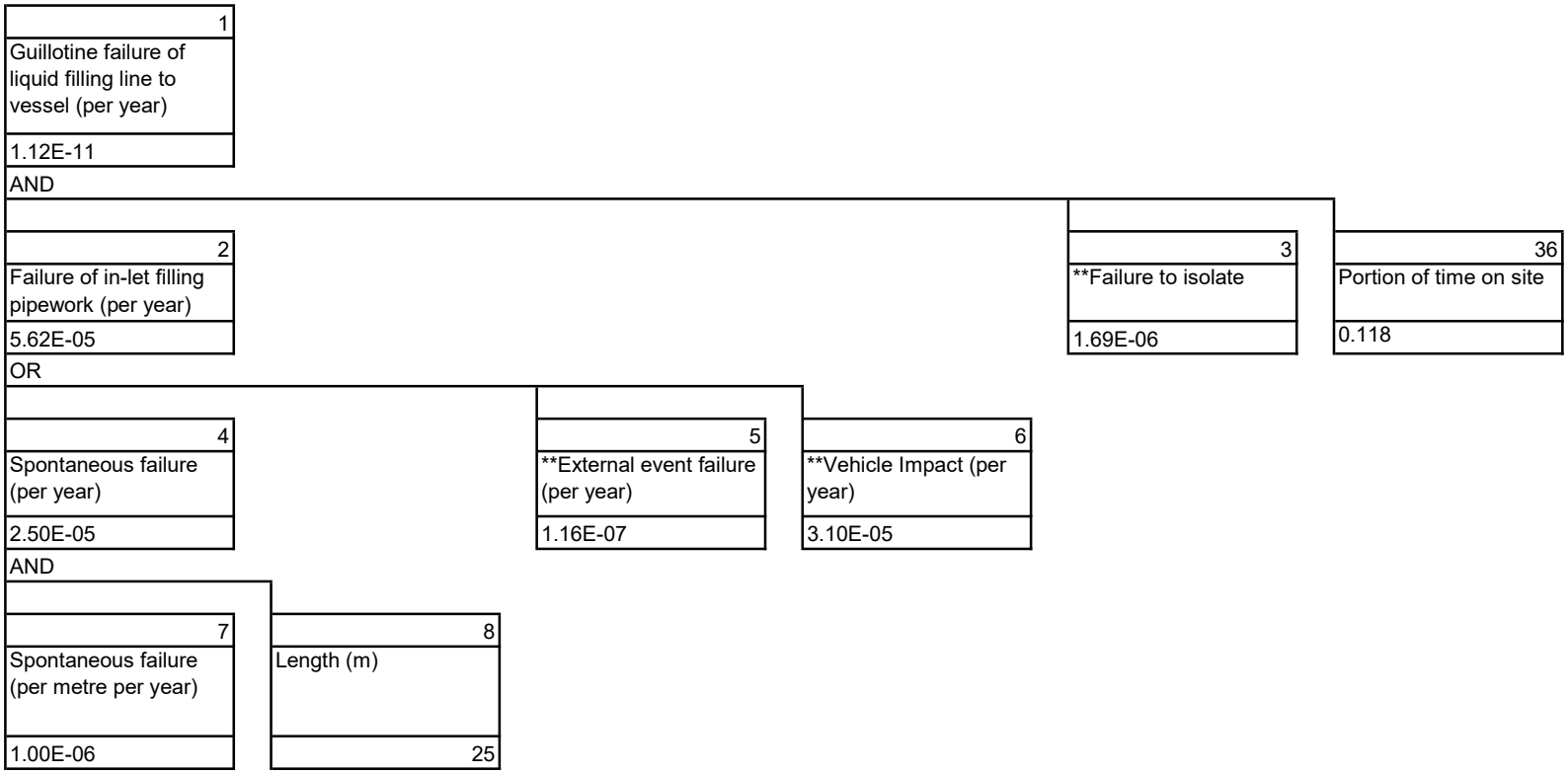
Annex B - Fault Tree Analysis

A-5a ***Guillotine Failure of In-let Filling Pipework (release from the vessel) (Con't)***



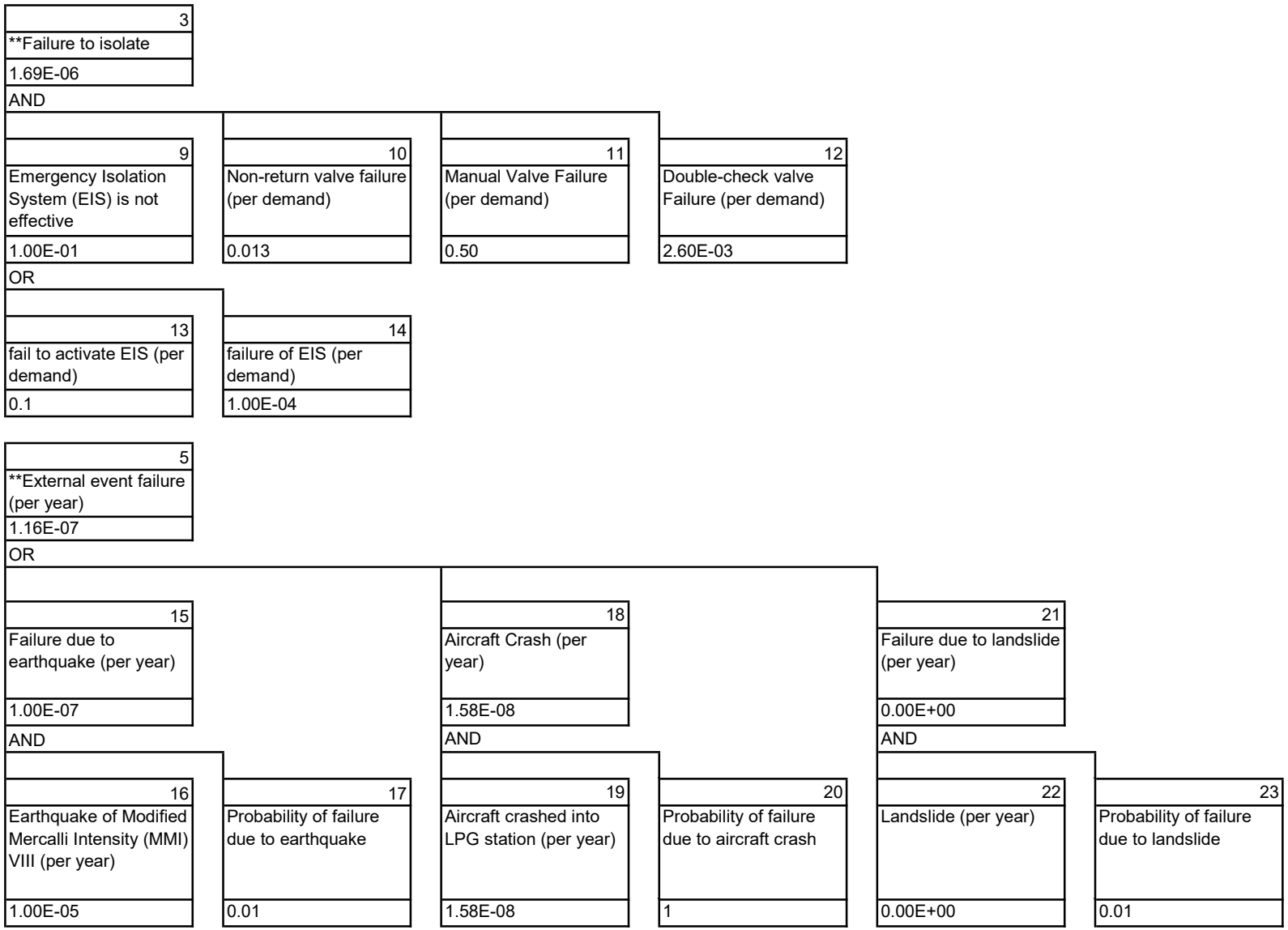
Annex B - Fault Tree Analysis

A-5b ***Guillotine Failure of In-let Filling Pipework (release from road tanker)***



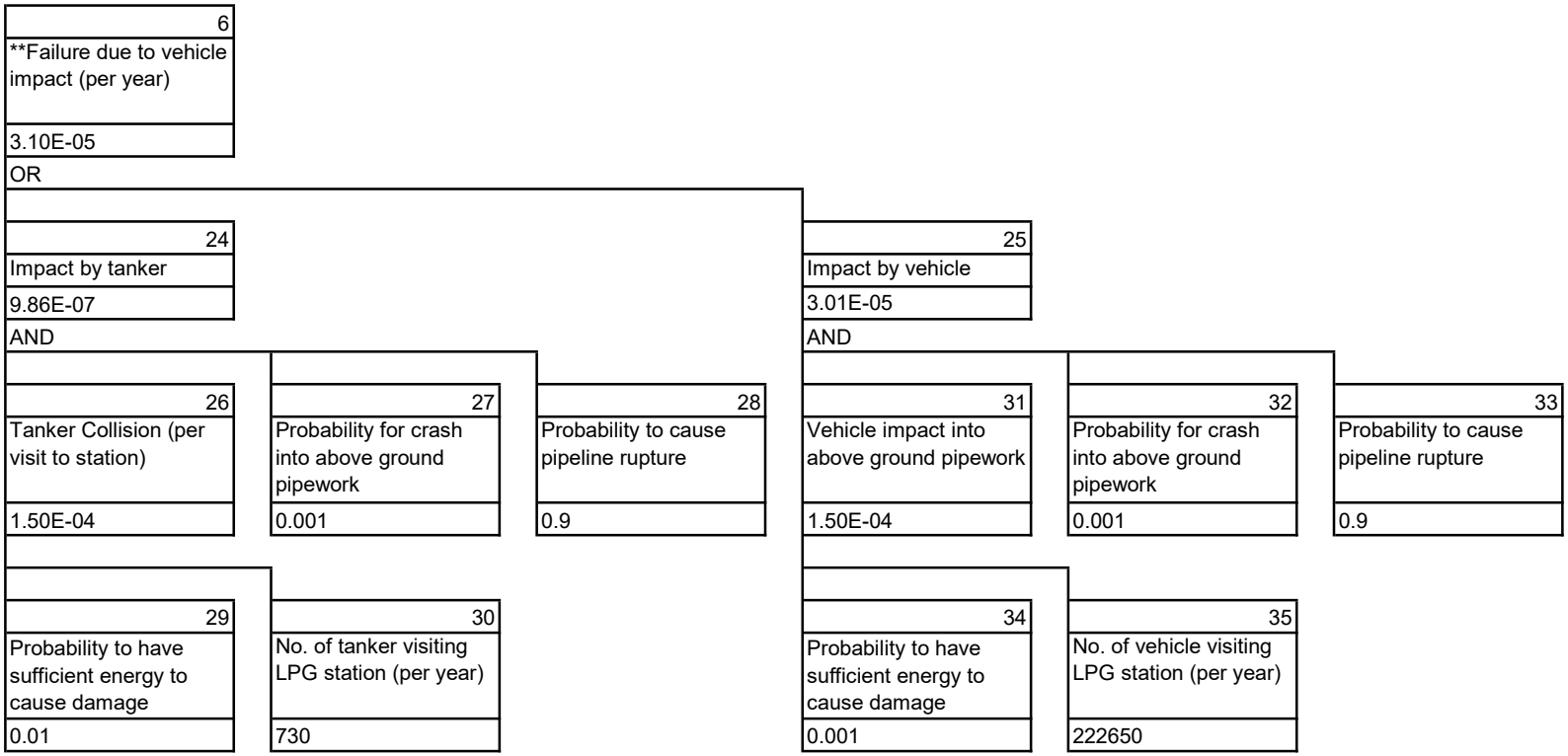
Annex B - Fault Tree Analysis

A-5b ***Guillotine Failure of In-let Filling Pipework (release from road tanker) (Con't)***



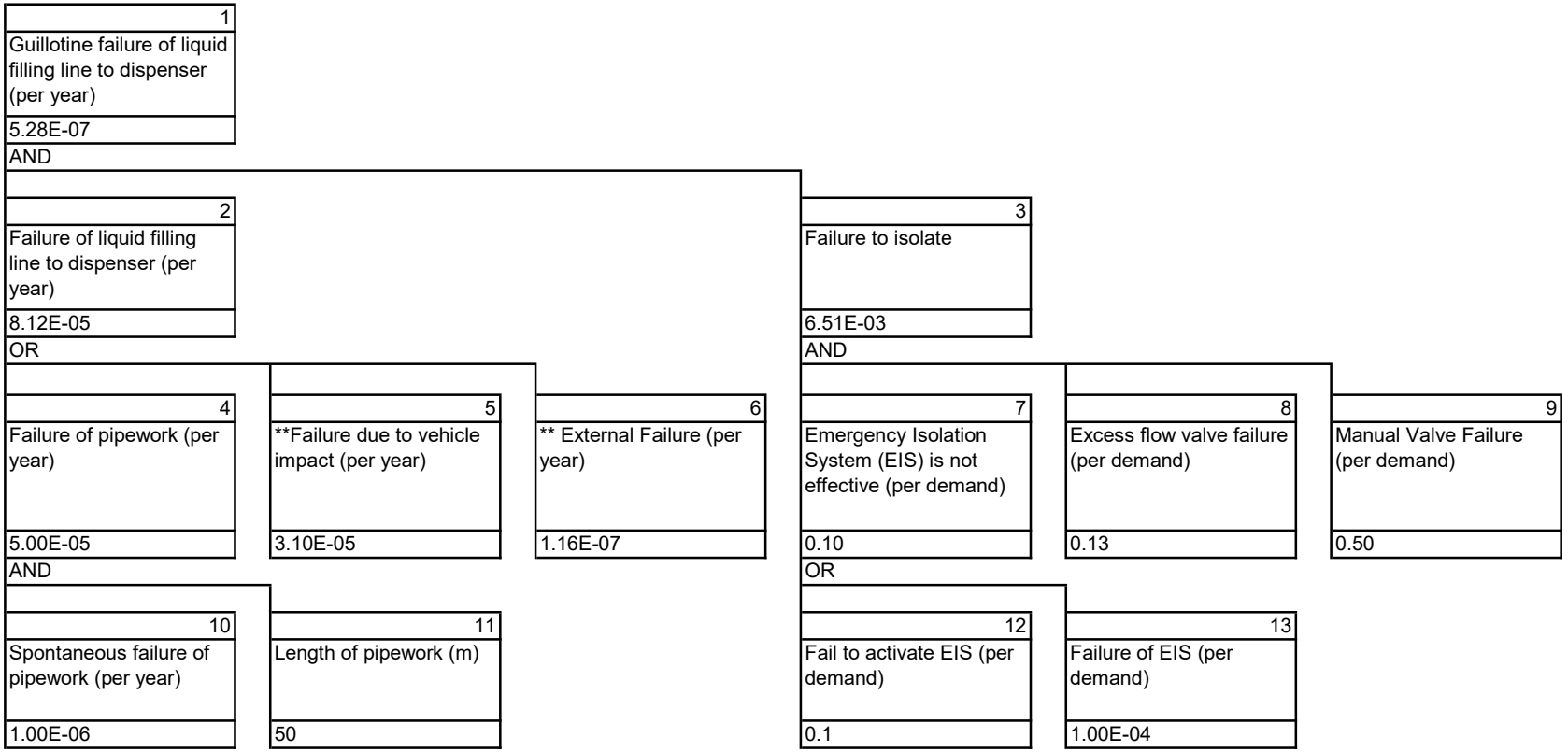
Annex B - Fault Tree Analysis

A-5b ***Guillotine Failure of In-let Filling Pipework (release from road tanker) (Con't)***



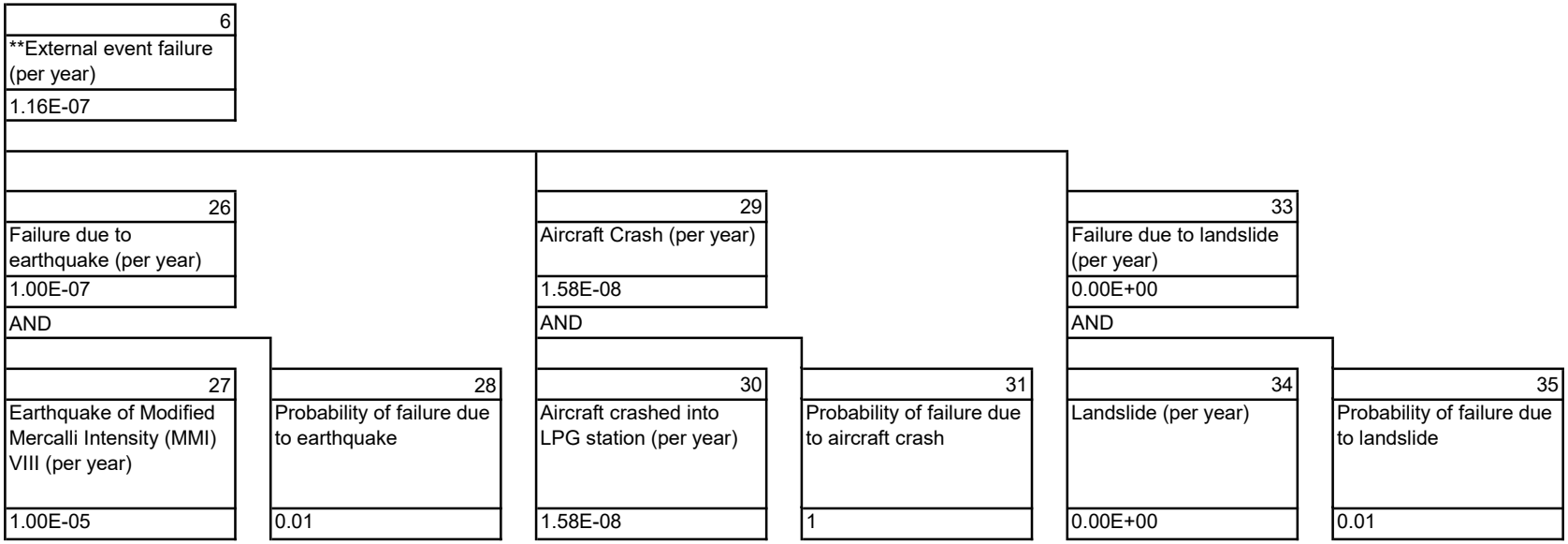
Annex B - Fault Tree Analysis

A-6 ***Guillotine Failure of Liquid Supply Line to Dispenser***



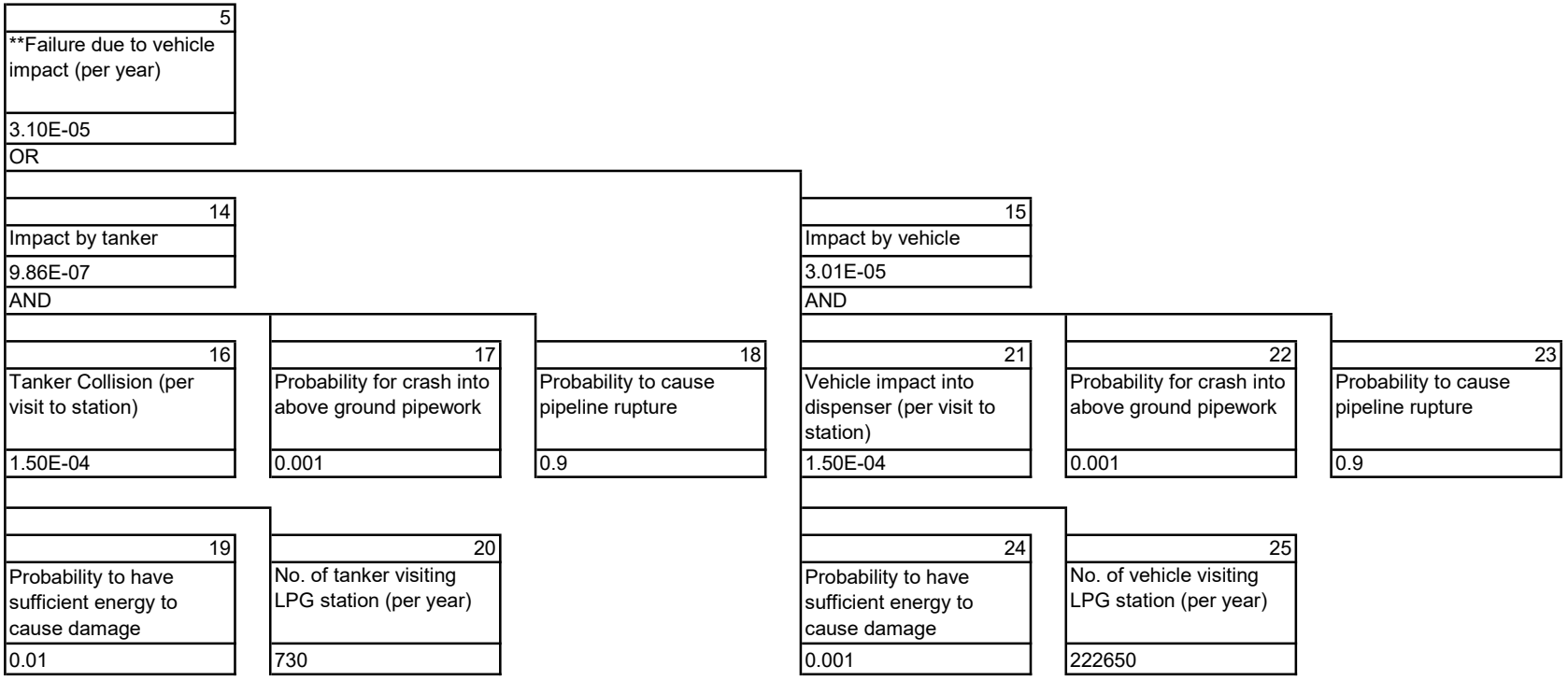
Annex B - Fault Tree Analysis

A-6 ***Guillotine Failure of Liquid Supply Line to Dispenser (Con't)***



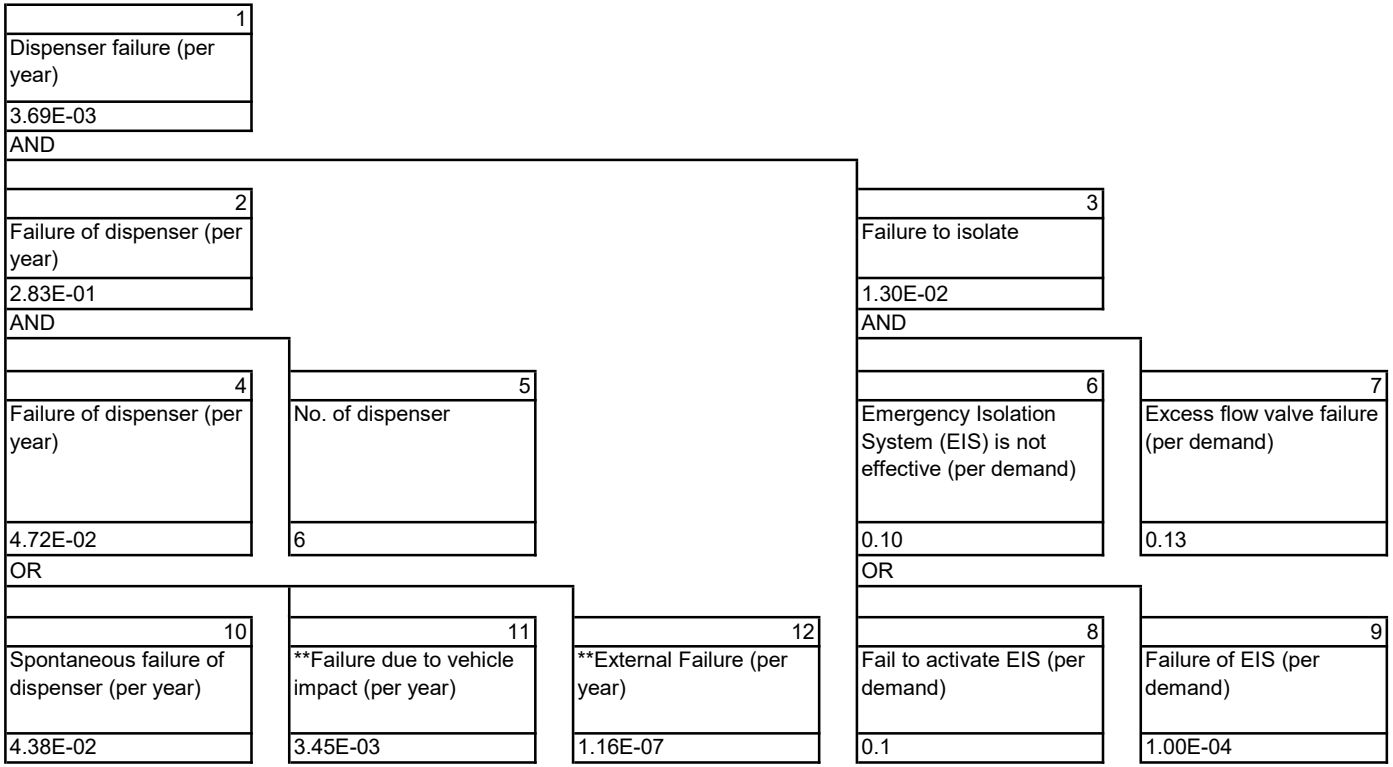
Annex B - Fault Tree Analysis

A-6 ***Guillotine Failure of Liquid Supply Line to Dispenser (Con't)***



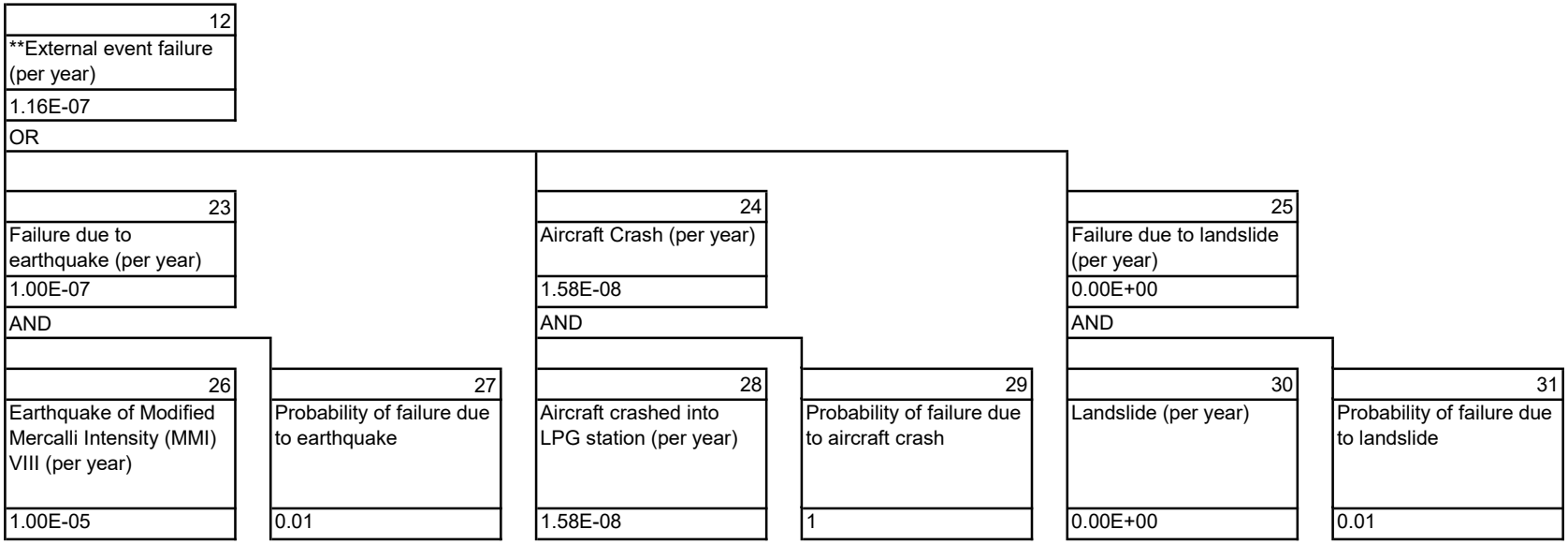
Annex B - Fault Tree Analysis

A-7 ***Failure of Dispenser***



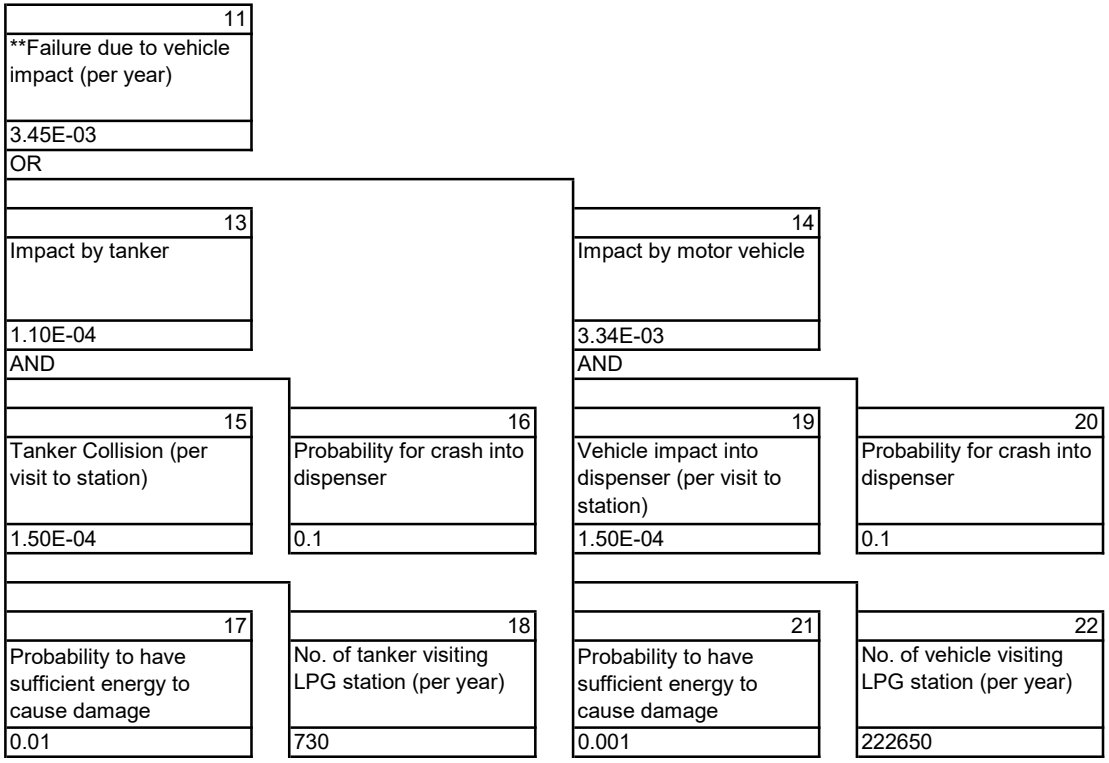
Annex B - Fault Tree Analysis

A-7 ***Failure of Dispenser (con't)***



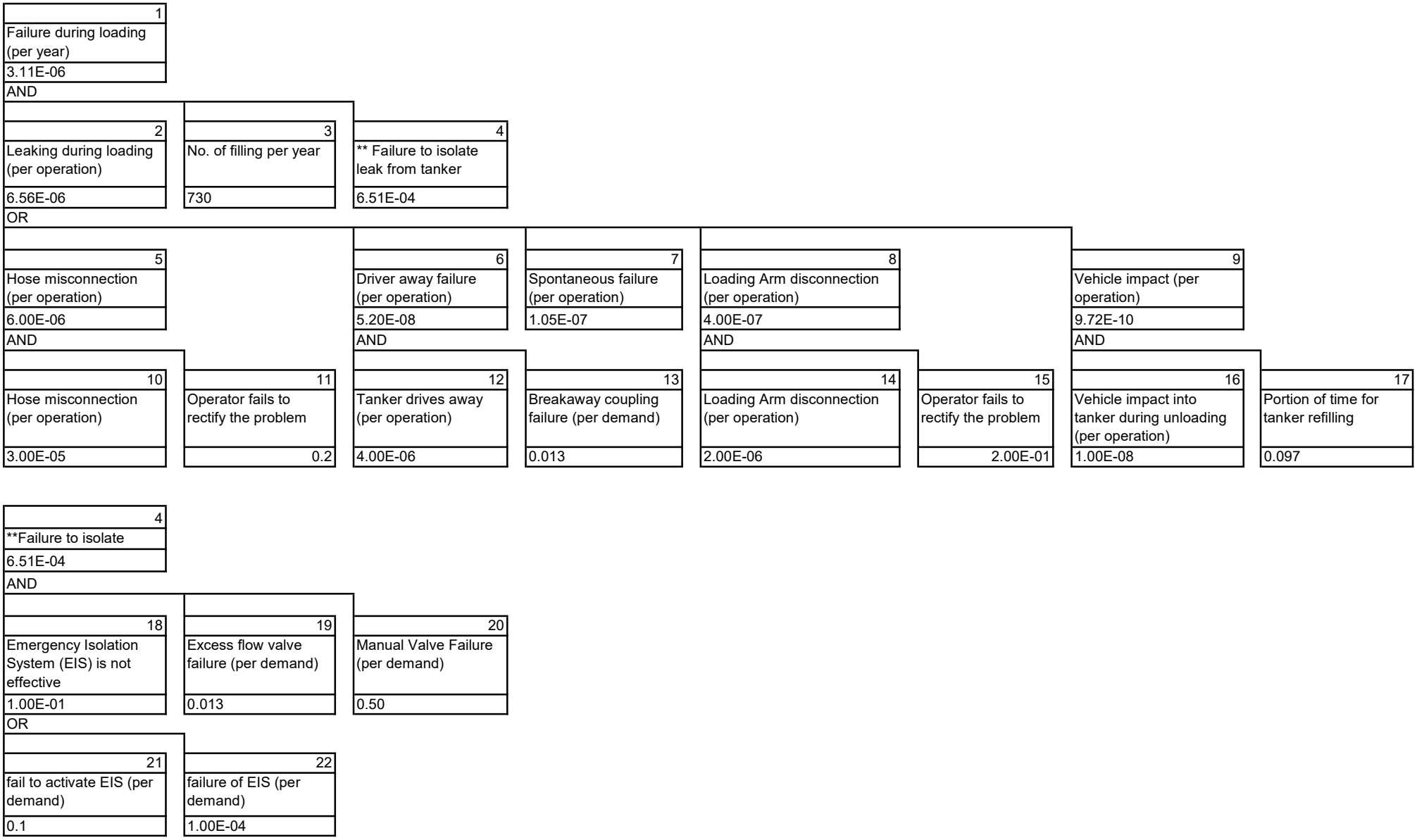
Annex B - Fault Tree Analysis

A-7 ***Failure of Dispenser (con't)***



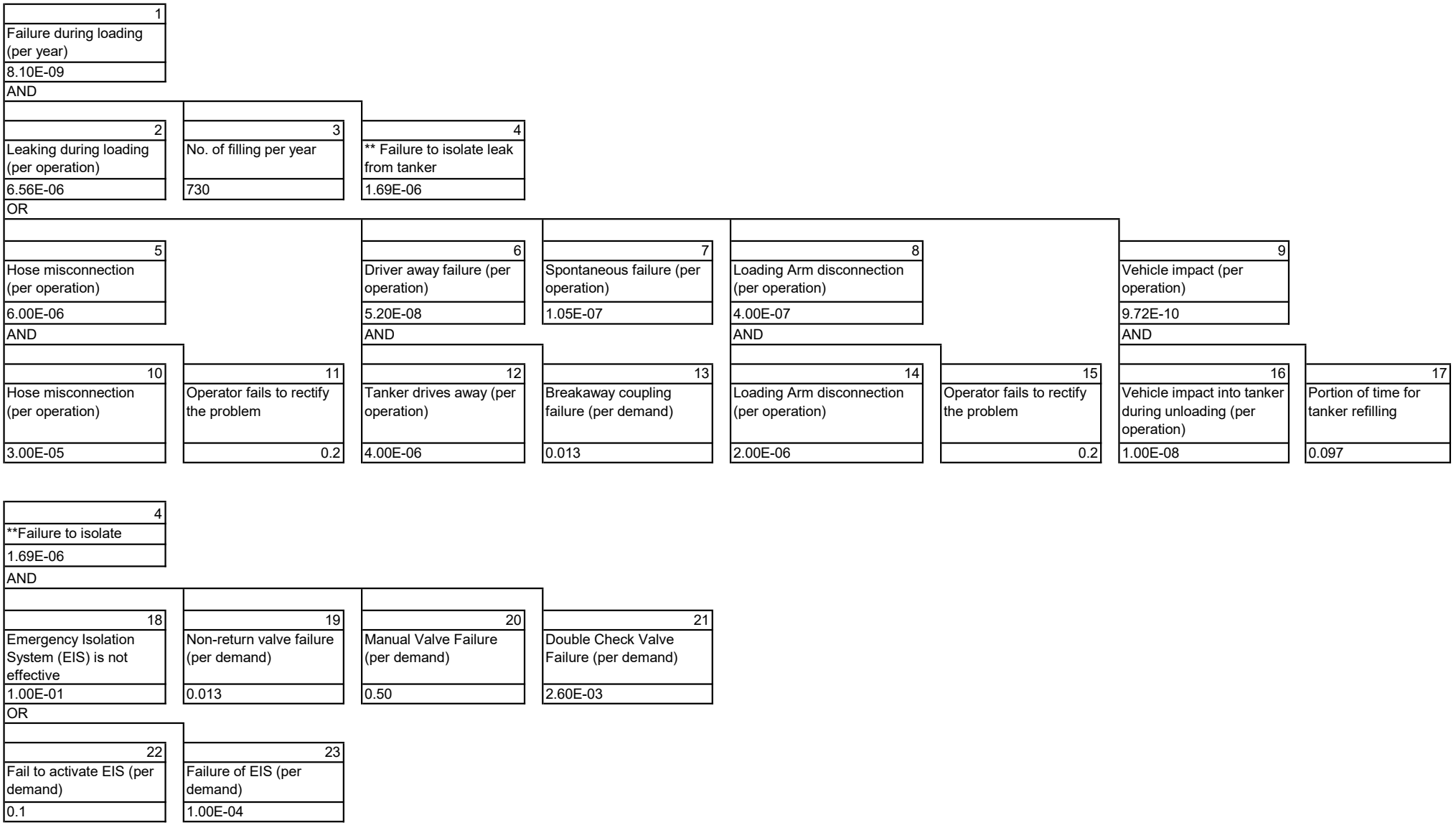
Annex B - Fault Tree Analysis

A-8a ***Failure of Flexible Hose during Loading to Storage Vessel (LPG released from the Hose Connecting to Road Tanker)***



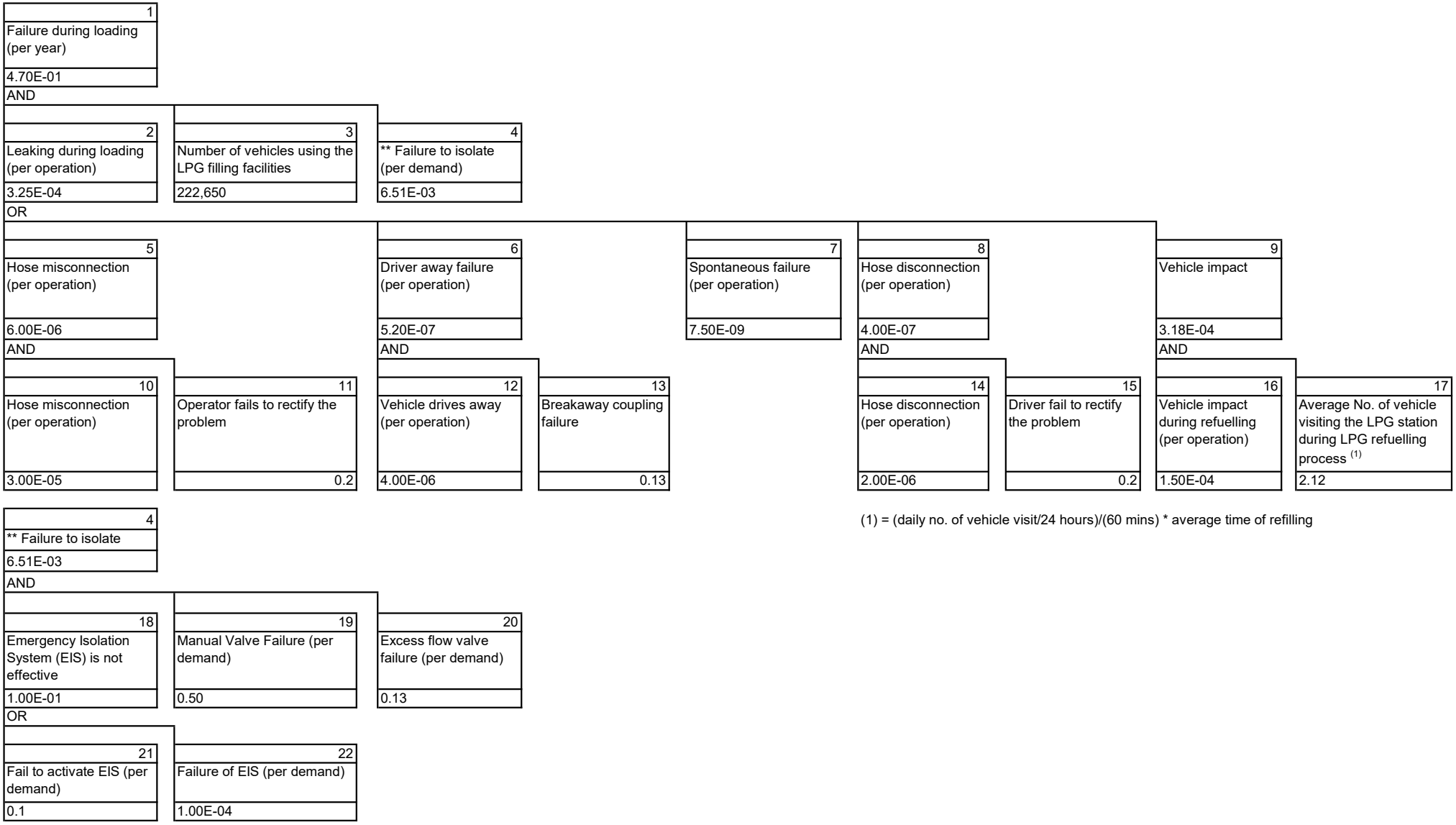
Annex B - Fault Tree Analysis

A-8b ***Failure of Flexible Hose during Loading to Storage Vessel (LPG released from the Hose Connecting to vessel)***



Annex B - Fault Tree Analysis

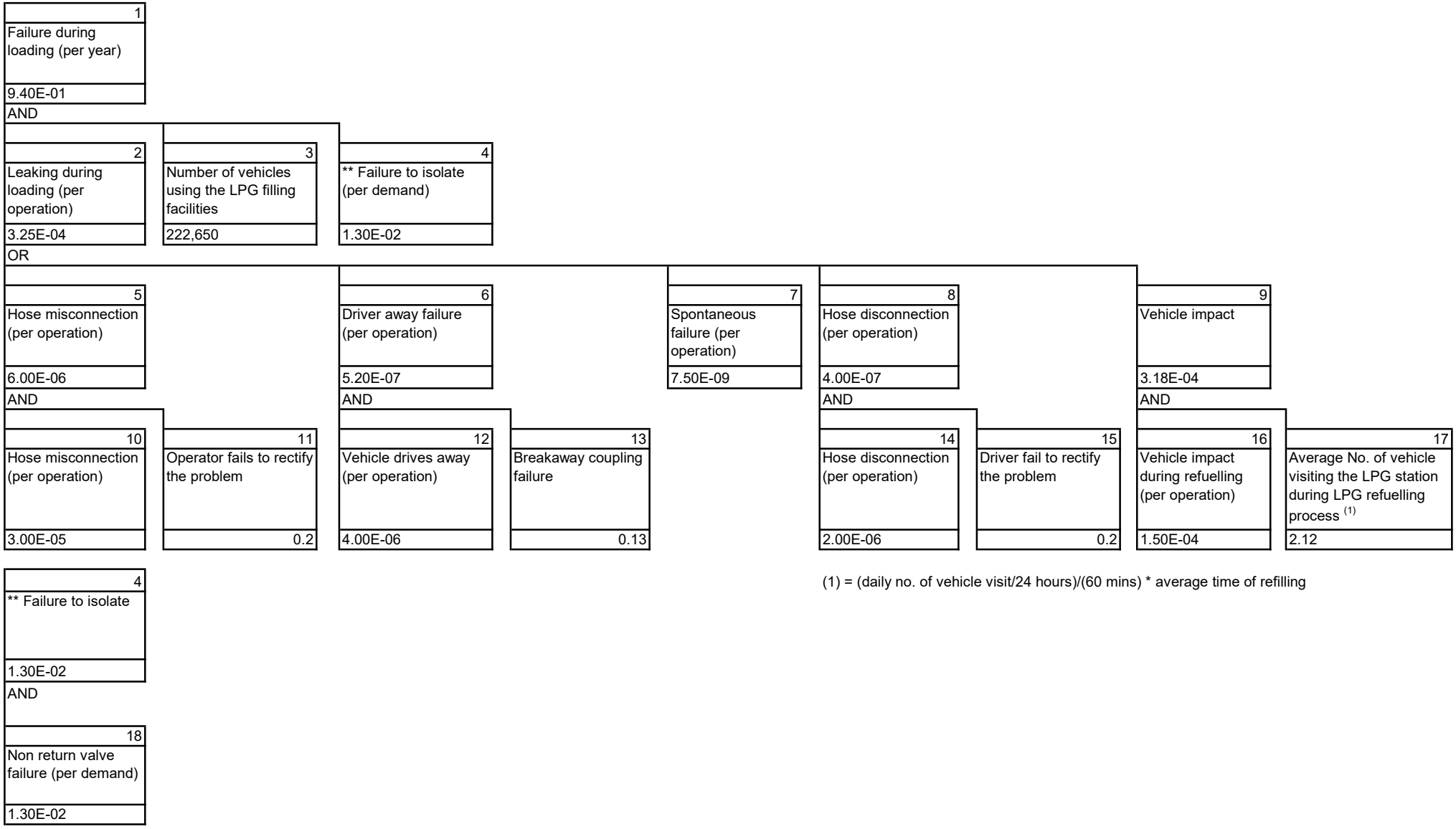
A-9a ***Failure of Flexible Hose during Loading to Vehicle (LPG released from the Hose Connecting to Dispenser)***



(1) = (daily no. of vehicle visit/24 hours)/(60 mins) * average time of refilling

Annex B - Fault Tree Analysis

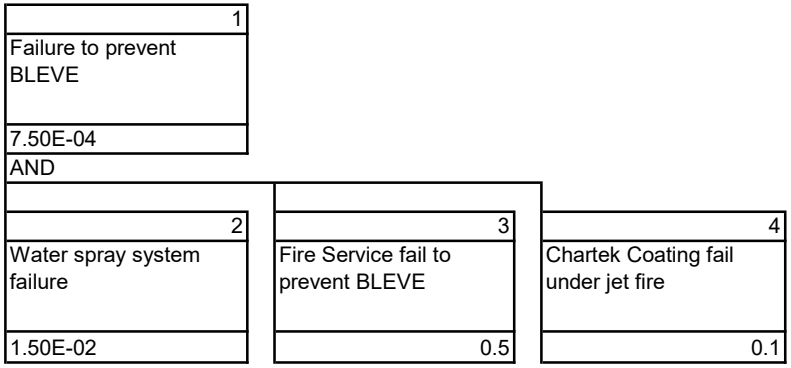
A-9b ***Failure of Flexible Hose during Loading to Vehicle (LPG released from the Hose Connecting to Vehicle)***



(1) = (daily no. of vehicle visit/24 hours)/(60 mins) * average time of refilling

Annex B - Fault Tree Analysis

A-10 ***Failure to Prevent BLEVE***



Annex B - Fault Tree Analysis

A-11 ***Leak From Pump Flange***

1
Leak from Pump Flange (per year)
4.36E-04

AND

2	3
Flange Failure (per year)	No. of Flange
1.09E-04	4

Annex B - Fault Tree Analysis

A-12 ***Leak From Drain Valve***

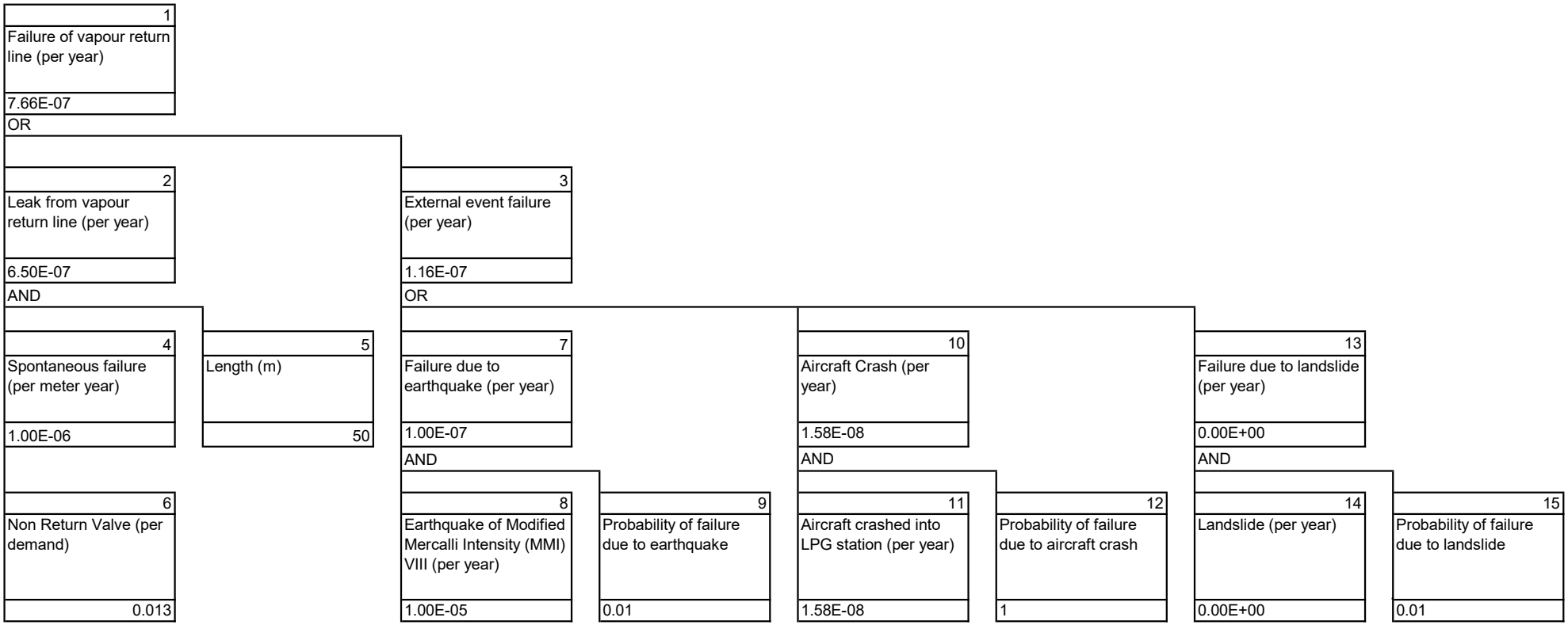
1
Leak from drain valve (per year)
4.80E-04

AND

2	3
Valve fails to close (per operation)	No. of operation per year
2.00E-05	24

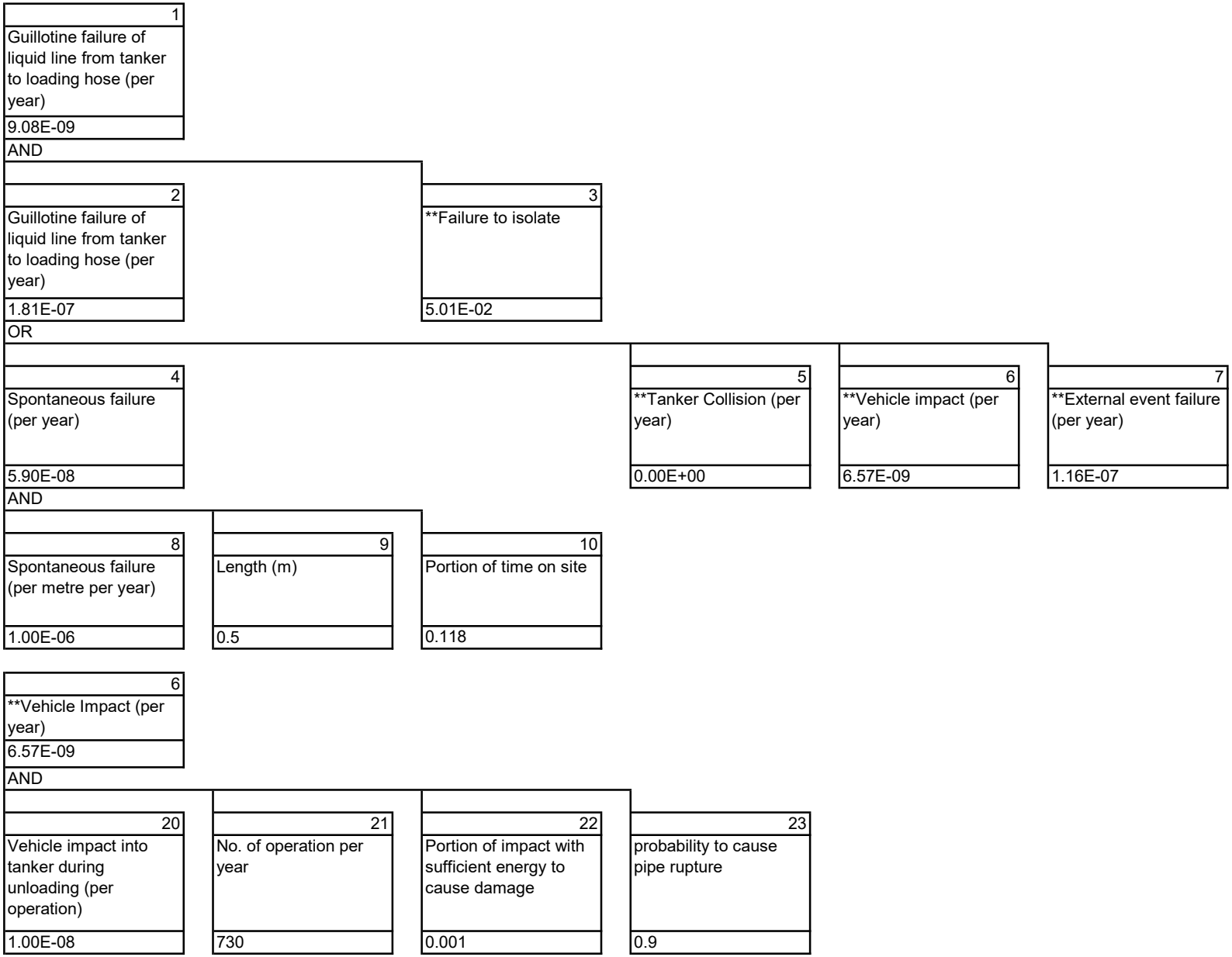
Annex B - Fault Tree Analysis

A-13 ***Failure of Vapour Return Line***



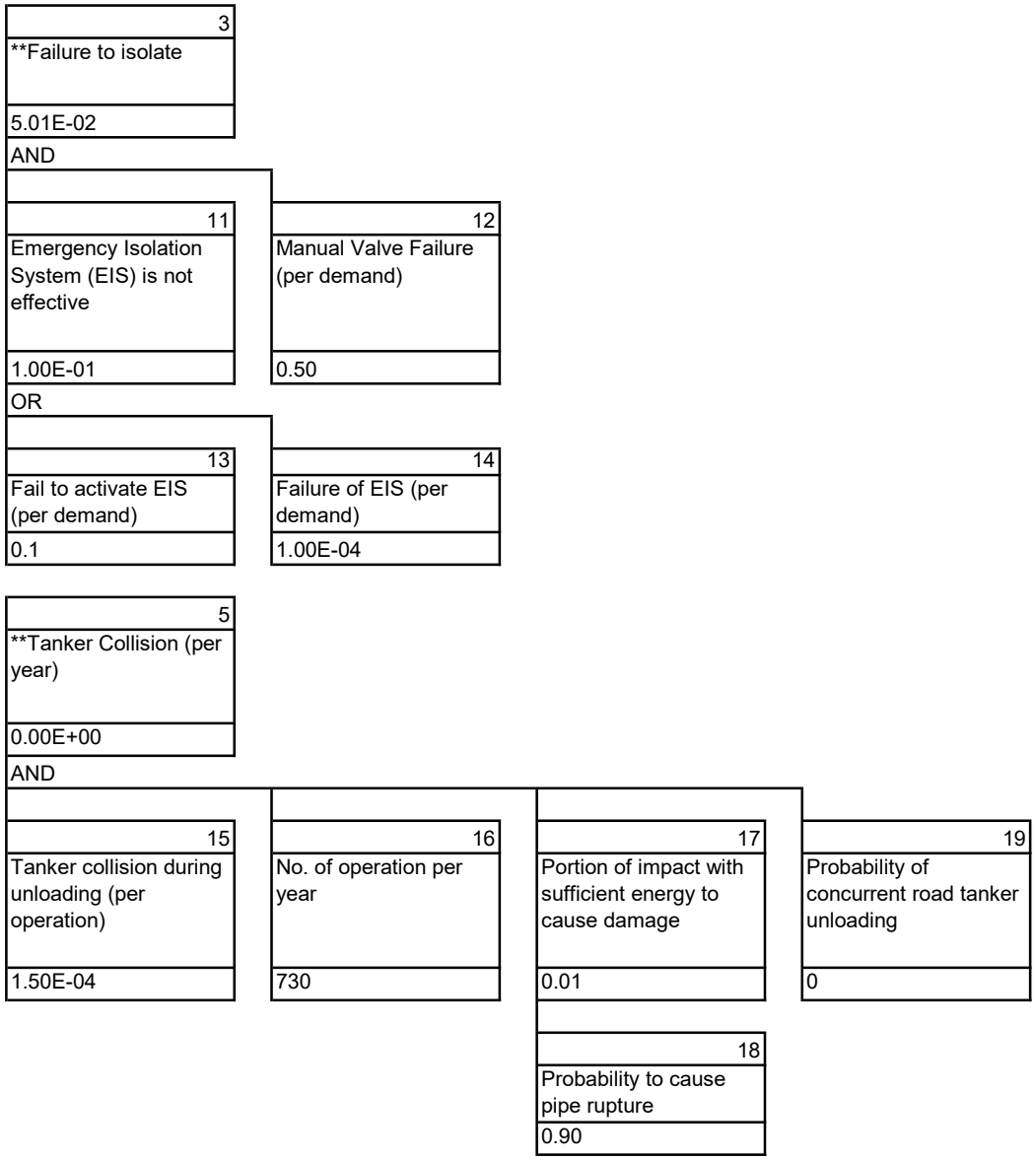
Annex B - Fault Tree Analysis

A-14 ***Guillotine Failure of liquid line from Road Tanker to loading hose***



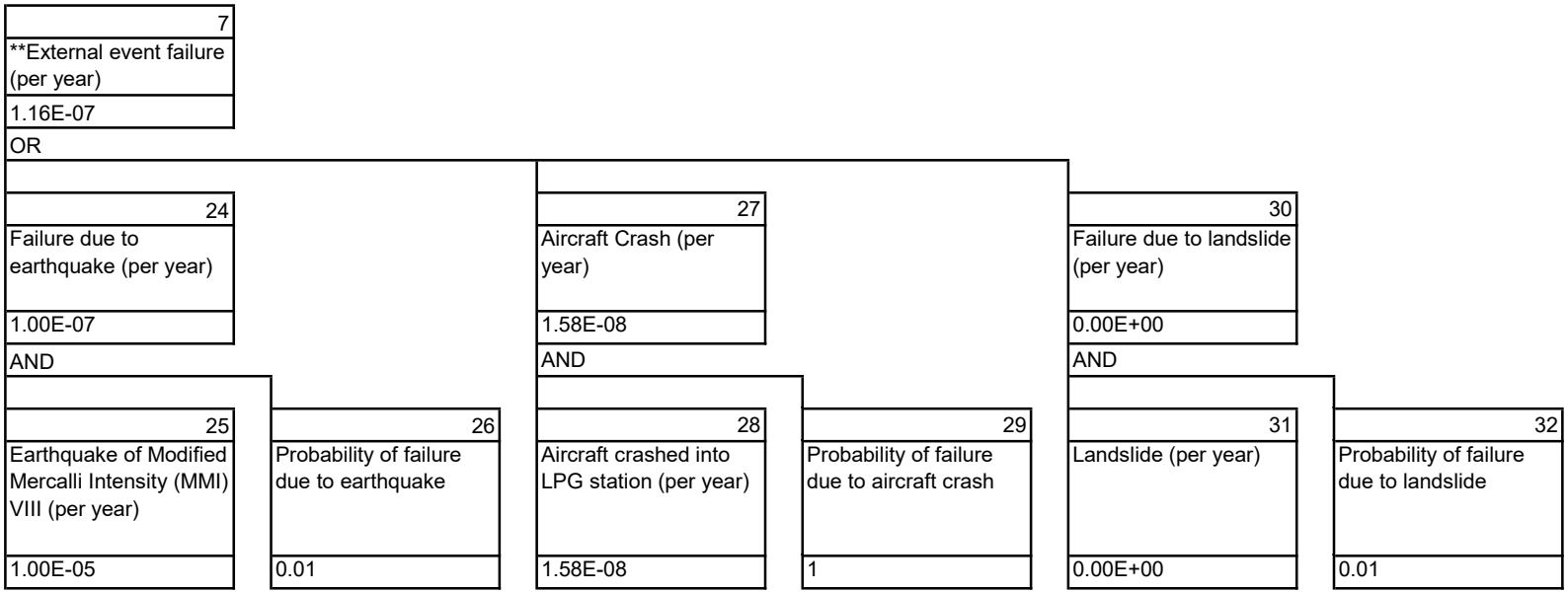
Annex B - Fault Tree Analysis

A-14 ***Guillotine Failure of liquid line from Road Tanker to loading hose (Con't)***



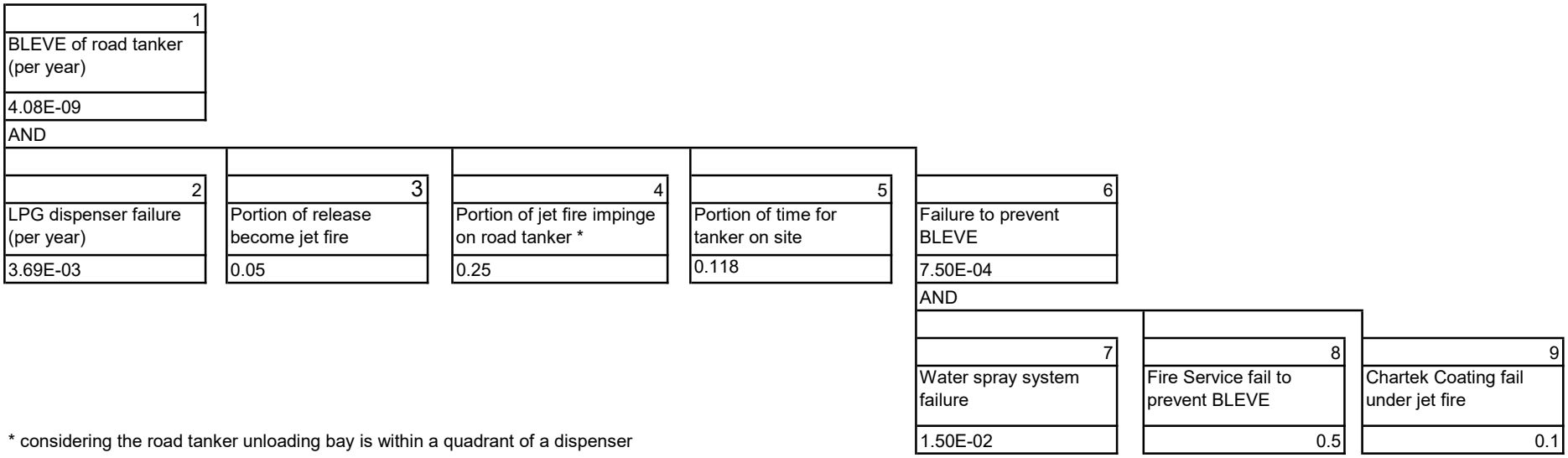
Annex B - Fault Tree Analysis

A-14 ***Guillotine Failure of liquid line from Road Tanker to loading hose (Con't)***



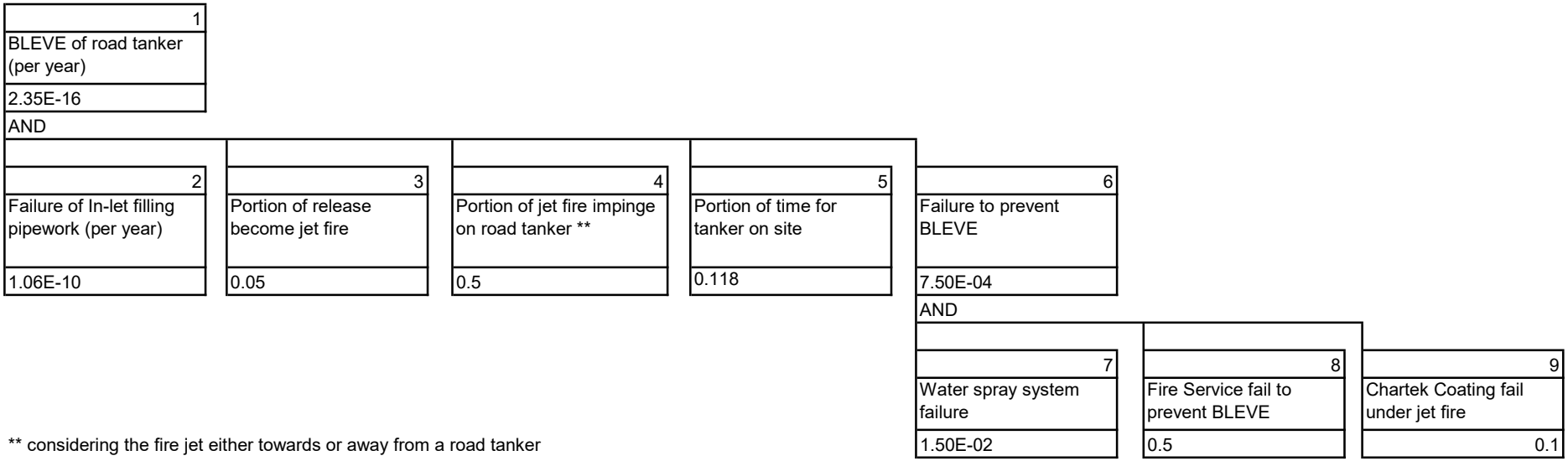
Annex B - Fault Tree Analysis

A-15a **BLEVE of LPG road tanker due to fire from LPG dispenser**



* considering the road tanker unloading bay is within a quadrant of a dispenser

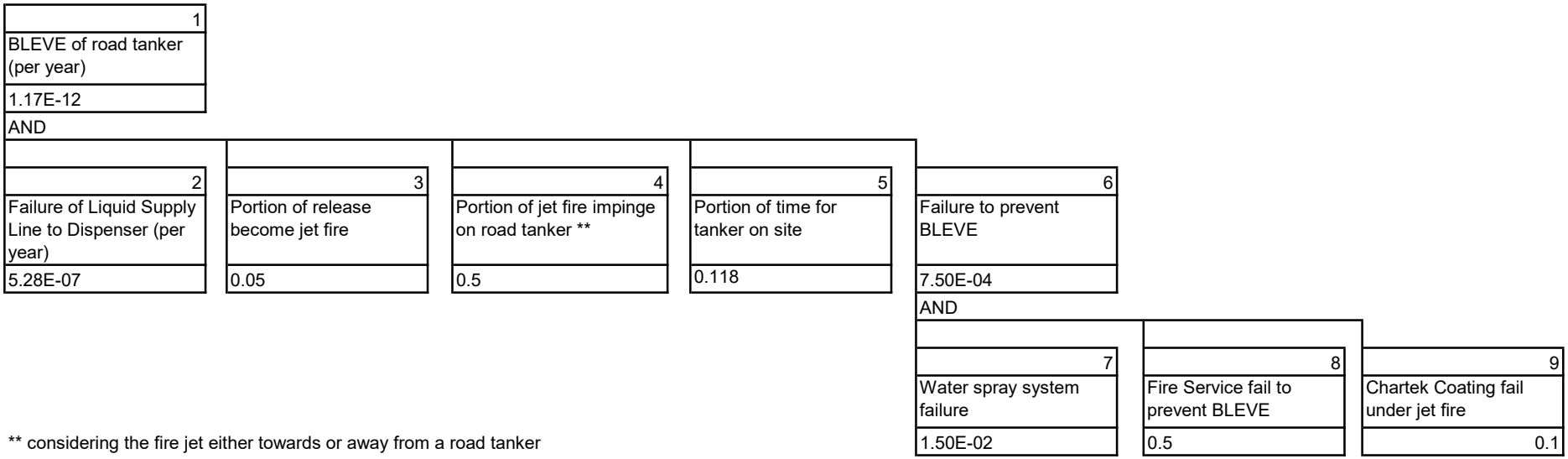
A-15b **BLEVE of LPG road tanker due to fire from in-let filling pipework**



** considering the fire jet either towards or away from a road tanker

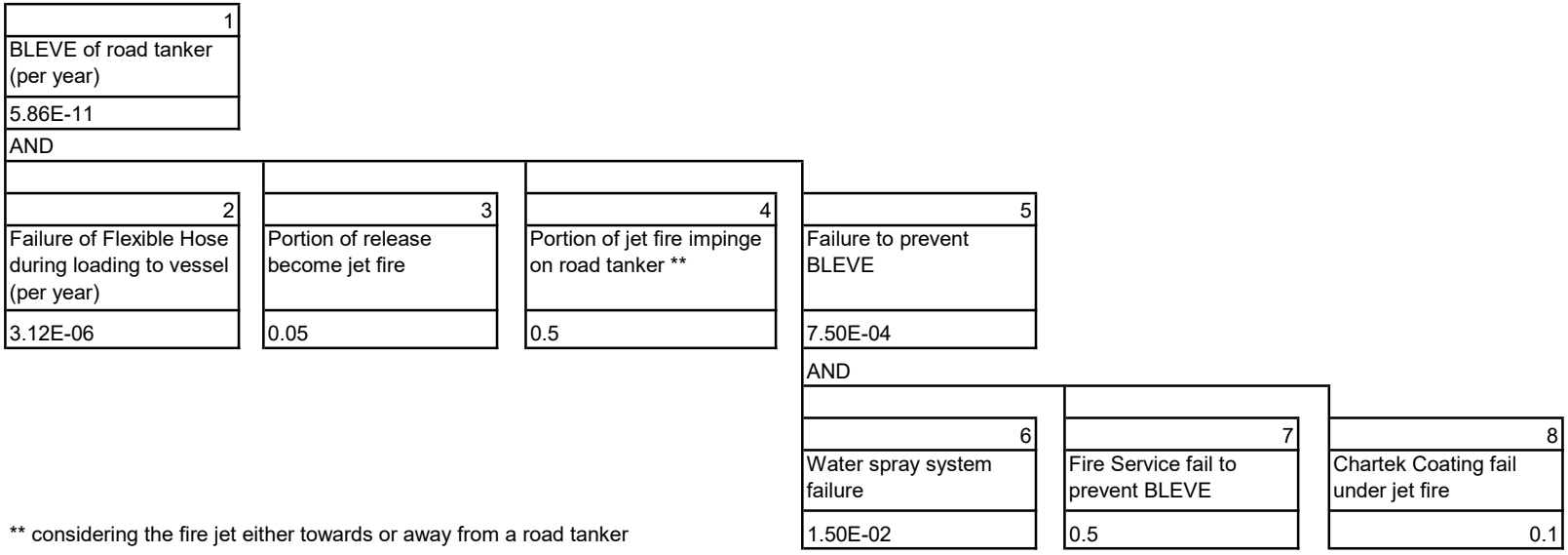
Annex B - Fault Tree Analysis

A-15c **BLEVE of LPG road tanker due to fire from liquid supply line to dispenser**



** considering the fire jet either towards or away from a road tanker

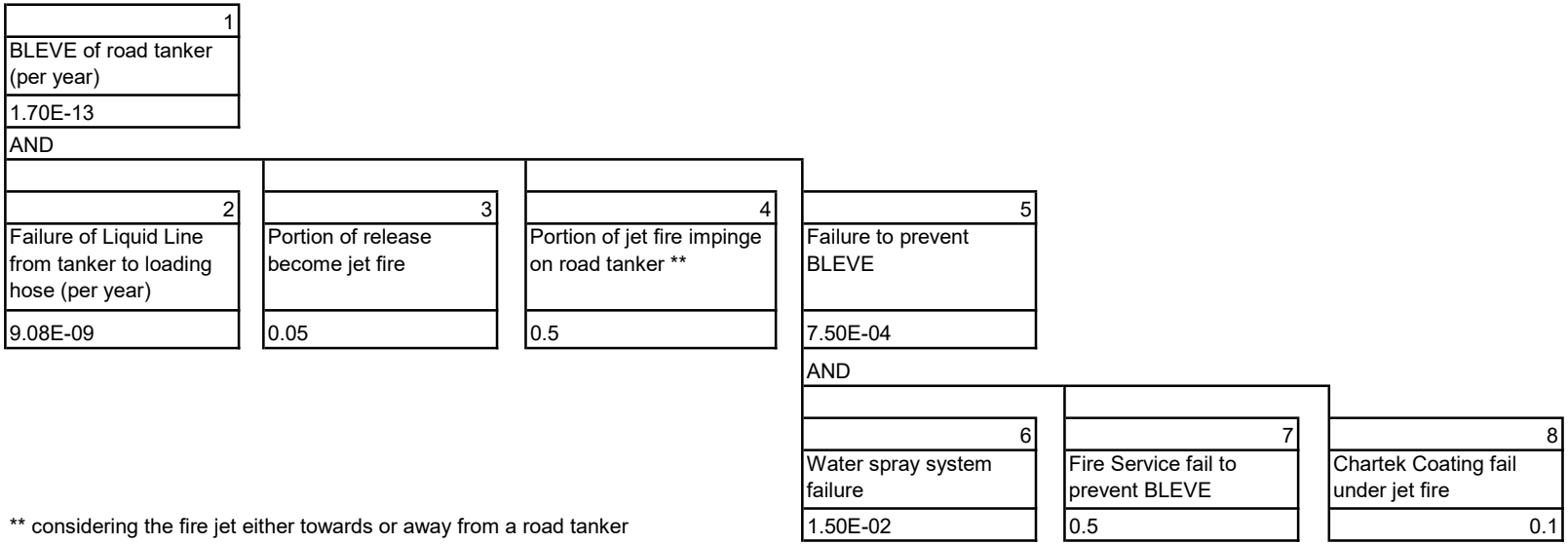
A-15d **BLEVE of LPG road tanker due to fire from loading arm during loading to underground vessel**



** considering the fire jet either towards or away from a road tanker

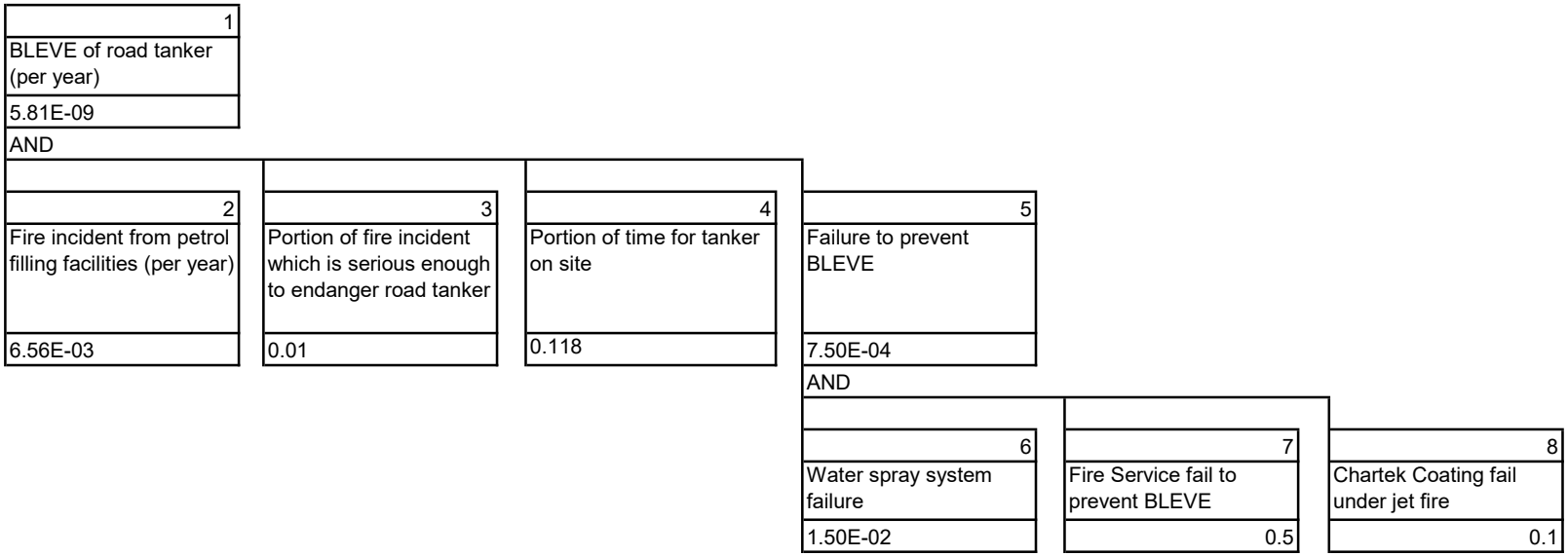
Annex B - Fault Tree Analysis

A-15e **BLEVE of LPG road tanker due to fire from liquid line (from tanker to loading hose)**



** considering the fire jet either towards or away from a road tanker

A-15f **BLEVE of LPG road tanker due to other fire incidents**

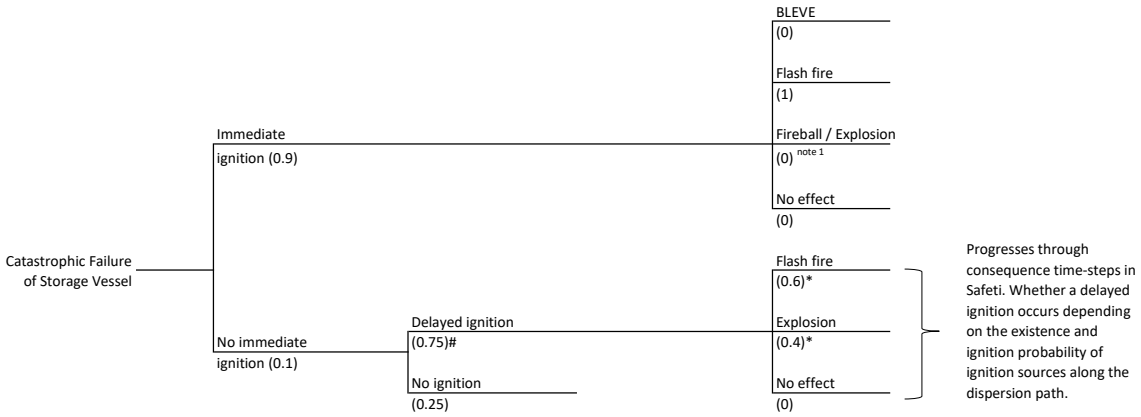


Annex C

Event Tree Analysis

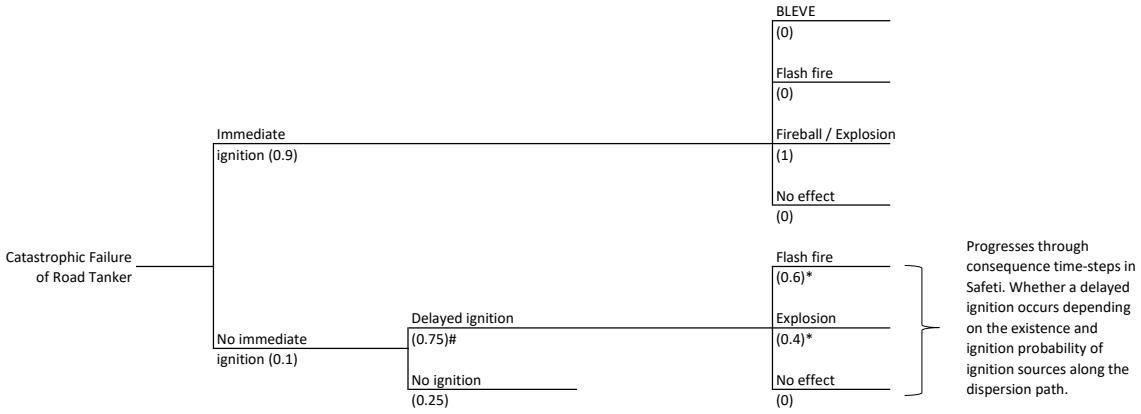
Annex C - Event Tree Analysis

Catastrophic Failure of Storage Vessel (Instantaneous release without rainout)



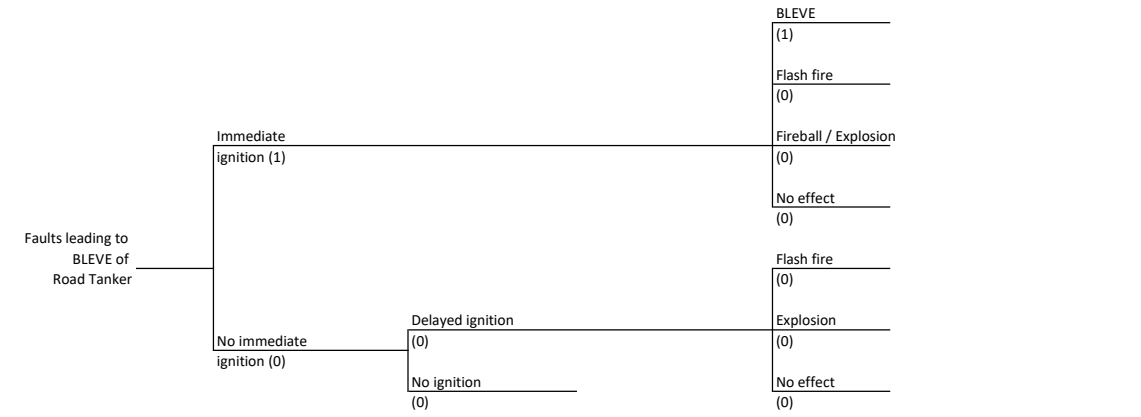
Note 1: applicable to mounded or underground tank only
* default in Safeti - based on TNO Purple Book
# delayed ignition probability varies from 0.4 to 0.75 for specified ignition sources and together with ignition due to population

Catastrophic Failure of Road Tanker (Instantaneous release without rainout)



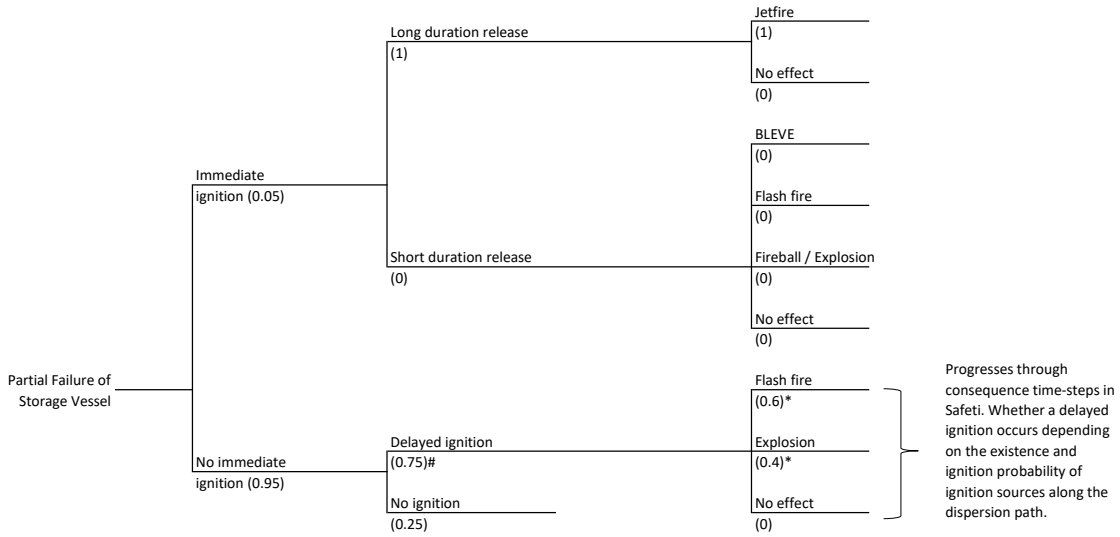
* default in Safeti - based on TNO Purple Book
# delayed ignition probability varies from 0.4 to 0.75 for specified ignition sources and together with ignition due to population

Fault leading to BLEVE of Road Tanker (Instantaneous release without rainout)



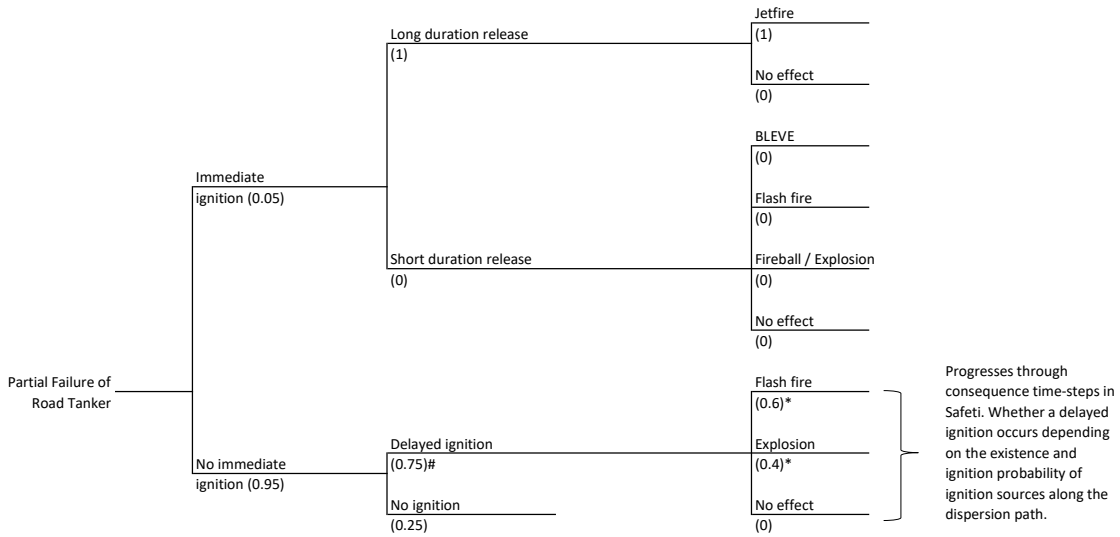
Annex C - Event Tree Analysis

Partial Failure of Storage Vessel (Continuous release without rainout)



* default in Safeti - based on TNO Purple Book
# delayed ignition probability varies from 0.4 to 0.75 for specified ignition sources and together with ignition due to population

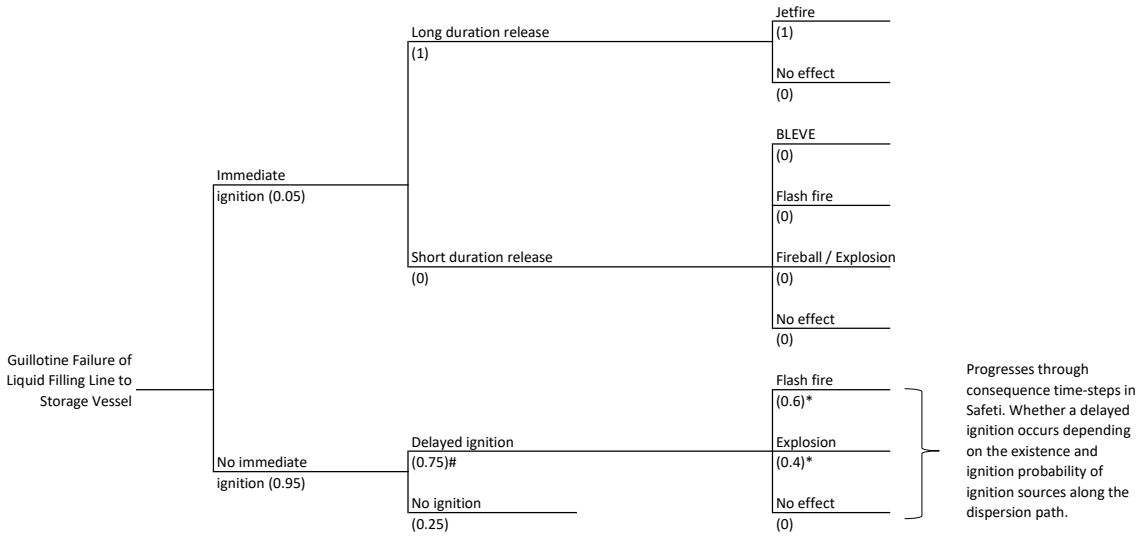
Partial Failure of Road Tanker (Continuous release without rainout)



* default in Safeti - based on TNO Purple Book
# delayed ignition probability varies from 0.4 to 0.75 for specified ignition sources and together with ignition due to population

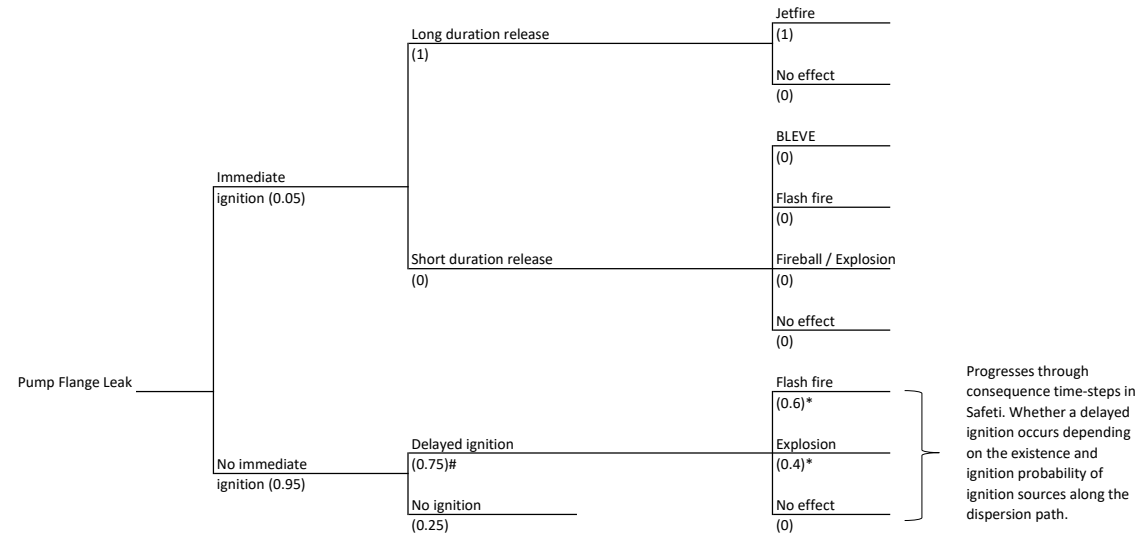
Annex C - Event Tree Analysis

Guillotine Failure of Liquid Filling Line to Storage Vessel (Continuous release without rainout)



* default in Safeti - based on TNO Purple Book
# delayed ignition probability varies from 0.4 to 0.75 for specified ignition sources and together with ignition due to population

Pump Flange Leak (Continuous release without rainout)



* default in Safeti - based on TNO Purple Book
# delayed ignition probability varies from 0.4 to 0.75 for specified ignition sources and together with ignition due to population